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Technical Report HL-93-6
July 1993

US Army Corps
of Engineers
Waterways Experiment
Station

Baldhill Spillway

Hydraulic Model Investigation

by *Bobby P. Fletcher*
Hydraulics Laboratory

Prepared for U.S. Army Engineer District, St. Paul

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Final report

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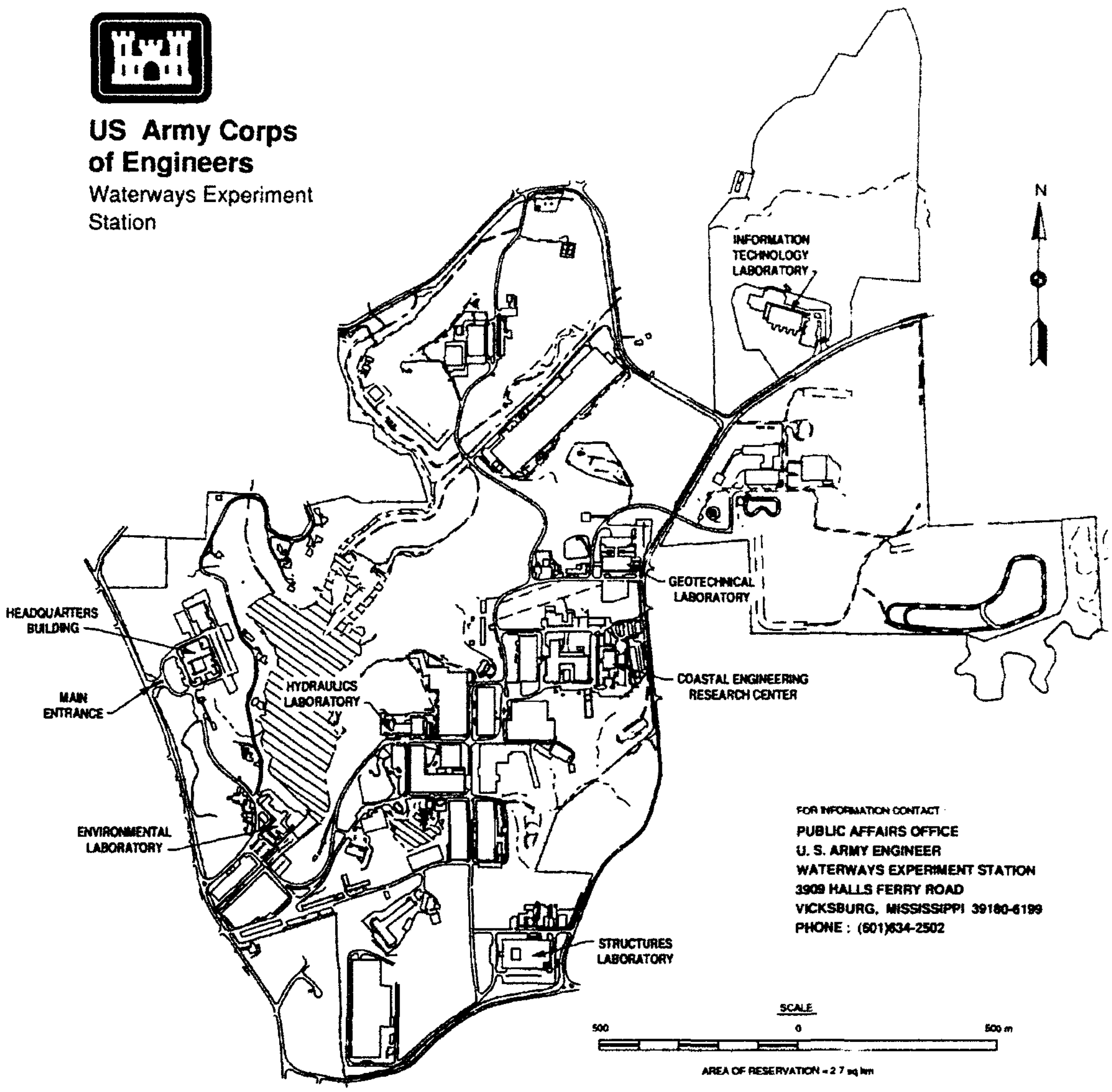

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Contents

Preface

The model investigation reported herein was authorized by the Headquarters, U.S. Army Corps of Engineers, on 1 October 1991 at the request of the U.S. Army Engineer District, St. Paul.

The study was conducted by personnel of the Hydraulics Laboratory (HL), U.S. Army Engineer Waterways Experiment Station (WES), during the period October 1991 to July 1992 under the direction of Messrs. F. A. Herrmann, Jr., Director, HL, and R. A. Sager, Assistant Director, HL, and under the general supervision of Messrs. G. A. Pickering, Chief of the Hydraulic Structures Division (HSD), HL, and N. R. Oswalt, Chief of the Spillways and Channels Branch, HSD. Project engineer for the model study was Mr. B. P. Fletcher, assisted by Mr. R. E. Bryant, both of HSD. Data collection and analysis support was provided by Messrs. H. C. Greer and T. W. Warren, Instrumentation Services Division, WES. This report was prepared by Mr. Fletcher.

During the model investigation, Messrs. Gregg Eggers and Kent Hokens, St. Paul District, visited WES to observe the model in operation and discuss the program of tests.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
feet of water (39.2° F[1])	2.98898	kilopascals
miles (U.S. statute)	1.609347	kilometres
[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.		

1 Introduction

The Prototype

Baldhill Dam and Reservoir (Lake Ashtabula) are in eastern North Dakota, about 75 miles[1] west of Fargo and 9 miles northwest of Valley City (Figure 1). Construction of the dam was completed in 1950. The existing spillway was designed in the late 1940's for a discharge capacity of 43,100 cfs at a headwater elevation of 1273.[2] The existing dam consists of a compacted earth-filled embankment and a combined gated spillway and low-flow outlet structure on the right abutment. The embankment elevation is 1278.5 and has a crest length of 1,650 ft. The average height from crest to toe is 41 ft; the maximum height is 61 ft at the old Sheyenne River channel. The spillway is a reinforced concrete structure with a gated ogee crest (el 1252) and chute terminating in a conventional, trapezoidal stilling basin. Reservoir pool levels are regulated by three 40-ft-wide by 15-ft-high tainter gates. Two 3-ft-diam culverts in the tainter gate piers are used for low-flow control.

The revised estimated peak discharge of the probable maximum flood (PMF) at the damsite is approximately 126,000 cfs, nearly twice the capacity of the existing gated spillway with reservoir water at the dam crest (el 1278.5). Construction of a new emergency spillway is proposed for the project to safely pass the PMF. The proposed ungated spillway concept (Plate 1) involves construction of an uncontrolled reinforced concrete chute spillway with stilling basin and end sill 800 ft wide through the central portion of the existing earth embankment. The crest of the new chute would be at el 1271, 7.5 ft below the crest of the existing earth embankment. Design water level for the PMF conditions would be el 1278.5, the same as the crest of the existing earth embankment. The unmodified portion of the embankment, surmounted by new reinforced concrete parapet walls, would provide a top elevation 5 ft above the maximum anticipated pool elevation.

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[1] A table of factors for converting non-SI units of measurement to SI units is presented on page v.

[2] All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

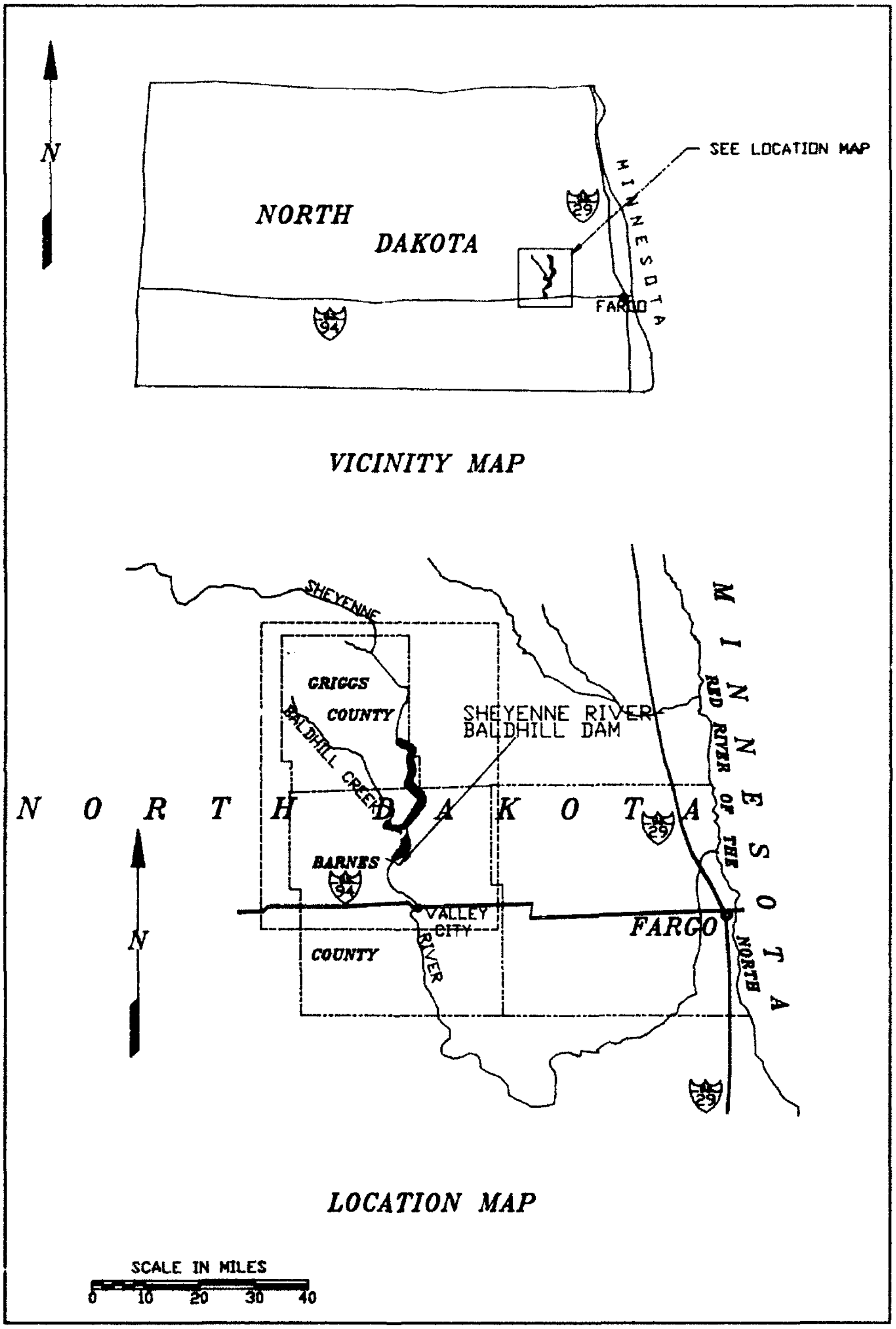


Figure 1. Location and vicinity maps

To pass the current design PMF, the spillway will be operated with a headwater up to el 1279.4 and a discharge of 65,000 cfs. The increased headwater elevation, tailwater elevation, and discharge will increase loading on the spillway's component structures. The additional tailwater elevation will move the hydraulic jump to a higher elevation on the existing spillway chute. In addition, the existing spillway was designed before the effects of dynamic pressure fluctuations or pulsation pressures were quantified or considered. There is concern that for spillway discharges much less than the PMF, pressure pulsations could cause severe damage or failure of the spillway chute and/or stilling basin. The pulsating pressures in the hydraulic jump have been identified as a potential major factor in evaluation of the safety of the structure and in development of designs for improvements if required.

Purpose and Scope of Model Study

The model study was conducted to determine for various flow conditions the frequency, magnitude, and areal extent of the hydraulic pulsating pressures acting on the surface (hydraulic jump side) of the spillway chute and stilling basin apron.

Pulsating pressures were measured for a range of hydraulic conditions that included symmetrical and asymmetrical spillway gate openings and the maximum anticipated discharge.

2 The Model

Description

The existing spillway was reproduced at a 1:30 scale in a flume that was 6 ft wide and 4 ft deep and had an effective length of 40 ft (Figure 2). One side of the flume was transparent to permit observation of flow patterns and turbulence. The size of the flume enabled simulation of the entire width and length of the spillway, which included the crest, gates, chute, and stilling basin (Plate 2). The approach and exit flow to and from the spillway was parallel to the longitudinal center line of the spillway and confined to a width of 180 ft (flume width).

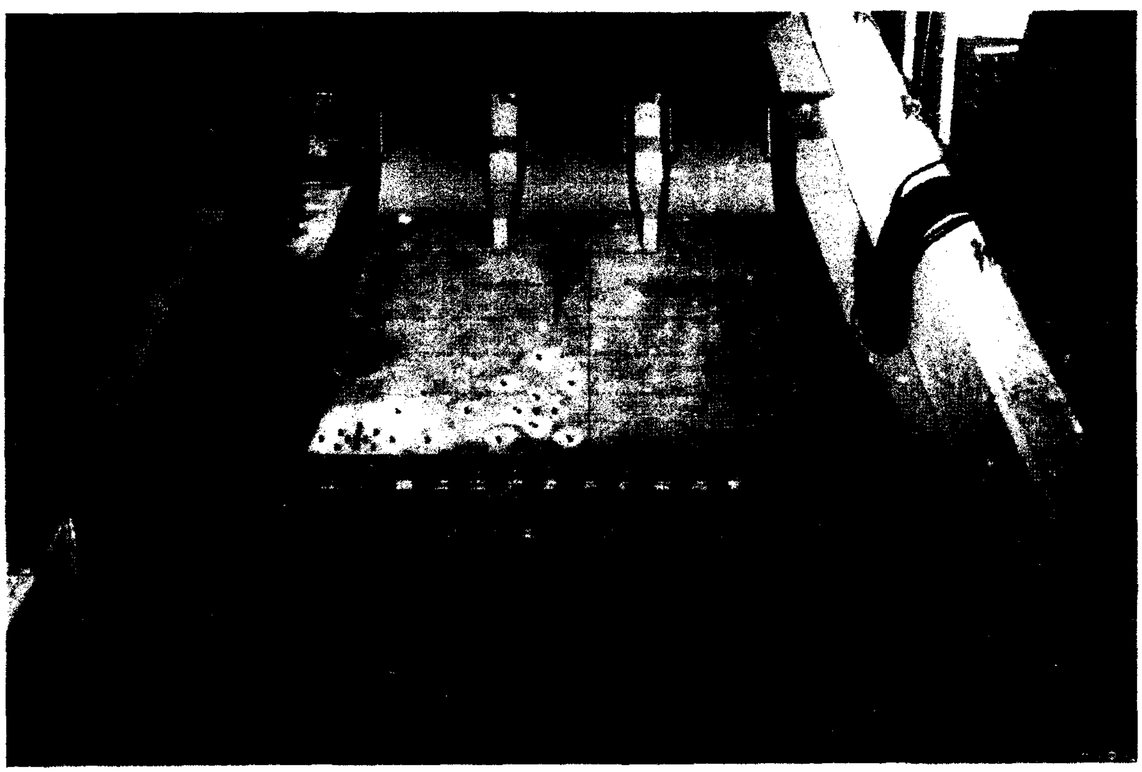


Figure 2. Model of existing spillway, upstream view

Transducers to measure the magnitude and frequency of the hydraulic forces were surface (flush) mounted in the spillway chute and stilling basin. The square flush-mounted surface of each transducer that sensed the pressure pulsations was 0.70 by 0.70 ft (prototype). The transducers measured the exciting pulsations only on the surface of the chute and apron.

Water used in the operation of the model was supplied by pumps and discharges were measured by venturi meters. Steel rails set to grade along the sides of the flume provided reference planes for measuring devices. Water-surface elevations were measured by means of point gages.

Interpretation of Model Results

The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and prototype. The general relations expressed in terms of the model's scale or length ratio L_r are expressed in the following tabulation:

Dimension	Ratio	Scale Relation Model:Prototype
Length	L_r	1:30
Area	$A_r = L_r^2$	1:900
Velocity	$V_r = L_r^{1/2}$	1:5.477
Discharge	$Q_r = L_r^{5/2}$	1:4,929
Time	$T_r = L_r^{1/2}$	1:5.477
Force	$F_r = L_r^3$	1:27,000
Frequency	$f_r = 1/L_r^{1/2}$	1:0.1826

3 Tests and Results

System Response

Initial tests were conducted to determine the natural frequency and damping characteristics of the submerged spillway chute and stilling basin apron. The natural frequency of the chute and stilling basin apron, measured to be about 22 cps (prototype), was considered too high to significantly influence the magnitude of the measured hydraulic forces. Tests also indicated no significant damping of the pressure pulsations.

Data Acquisition

Pressure pulsations acting on the spillway chute and stilling basin apron were detected by 30 surface-mounted transducers. The data acquisition system was capable of simultaneously measuring the pressure pulsations detected by the 30 transducers and sampling each transducer for various lengths of time and sampling rates.

Typical Tests

A typical test involved calibrating and zeroing the transducers; setting the spillway gate opening, discharge, and tailwater; allowing the pools to stabilize; and then collecting data from the transducers for a specified period of time. Following data collection for each test, the post-test transducer zeros were compared with the pretest zeros to confirm that there was no significant electronic drift.

Pressure Pulsations

Flow patterns in the chute and stilling basin were symmetrical due to the spillway's symmetrical design and the simulation of static upper and lower pool conditions. Due to the symmetry of the geometry and hydraulic conditions, it was considered that the exciting hydraulic forces would be symmetrical about the longitudinal center line of the chute and stilling basin. Thus, 30 transducers to simultaneously measure the magnitude and frequency of the hydraulic forces were surface (flush) mounted and located on one side of the longitudinal center line (Plate 3, type 1 transducer pattern). Various flow conditions that were investigated are illustrated in Photo 1.

To determine the best procedure for conducting tests, initial tests were conducted with various flow conditions and with discharges as high as the maximum probable discharge of 65,000 cfs. Data were collected for 1,640 and 98,600 sec (prototype) and were sampled at frequencies ranging from 9.13 to 91.3 samples per second (prototype). After analyzing the initial tests, it was decided to conduct all of the remaining tests for 19,718 sec and sample at a frequency of 9.13 samples per second.

The 10 tests conducted with the type 1 transducer pattern (Plate 3) are shown in Table 1. For Tests 1-8, Tables 2-9 provide the transducer number and minimum, average, and maximum value of pressures that were recorded at a rate of 9.13 samples per second during a 19,718-sec period. Time-history plots recorded during Test 1 (maximum discharge simulated, Table 1) are shown in Plate 4. Visual inspection of the plots indicated that there was no correlation between extreme pressure pulsations. Transducer 20 (Table 2 and Plate 4), Test 1, experienced a minimum pulsation of -4.5 ft of water. To evaluate this minimum pulse, the time frame was expanded in a series of time-history plots, as shown in Plate 5. To further evaluate the pulse at a faster sampling rate, the hydraulic conditions in Tests 1 and 8 were rerun (Tests 9 and 10, Table 1), and data were collected for a 1,643-sec period at a rate of 91.3 samples per second. The magnitude of the pulses was similar to those measured at a sampling rate of 9.13 samples per second. The minimum pulsation in Test 9 was detected by transducer 21. Expanding time-history plots for transducer 21 in Test 9 are shown in Plate 6. Pressure contours were plotted to illustrate the pressure patterns when the instantaneous sum of the 30 transducers during the 19,718-sec run was at its minimum value. Pressure contour plots for Tests 1-8 are shown in Plate 7.

Some transducers were relocated on a 2.5-ft grid pattern to increase their density in some areas, as shown in Plate 8 (type 2 transducer pattern).

Tests 11-18 (Table 10) were conducted with the type 2 transducer pattern and identical hydraulic conditions to Tests 1-8. For Tests 11-18, Tables 11-18 provide the transducer number and minimum, average, and maximum value of pressures that were recorded at a rate of 9.13 samples per second during a 19,718-sec period of time. Time-history plots recorded for Test 11 (maximum discharge simulated, Table 10) are shown in Plate 9. Analysis of the plots indicated that there may be some correlation among the minimum pressure pulses measured by transducers 21, 35, and 36. These three transducers simultaneously detected a negative pulse, as illustrated by the expanded time frames in Plate 10.

Pressure contours plotted to illustrate the pressure patterns when the instantaneous sum of the 30 transducers during the 19,718-sec run was at its minimum negative value are shown in Plate 11. During Test 11, a minimum negative pulsation of -17.4 ft of water was recorded. A series of pressure contours shown in chronological order (Plate 12) depicts the pressure contours before, during, and after the negative pulsation of -17.4 ft of water occurred.

Tests were conducted with asymmetrical spillway gate openings to determine if asymmetrical flow patterns would increase the magnitude of the pressure pulsations. The three flow conditions investigated are described in Table 19. To ensure that the transducers were located in turbulent areas, the three flow conditions were simulated to define the turbulent areas to enable proper relocation of the transducers (type 3 transducer pattern). The type 3 transducer pattern is shown in Plate 13. The three flow conditions are shown in Photo 2. The minimum, average, and maximum values of pressure for the three flow conditions (Tests 19-21) were recorded at a rate of 9.13 samples per second during a 19,718-sec period (Tables 20-22). The minimum pulsation of -5.6 ft of water occurred during Test 21 at transducer 21 (Table 22). A time-history plot of transducers 21, 44, and 45 is shown in Plate 14. Pressure contours to illustrate the pressure patterns when the instantaneous sum of the 30 transducers during each 19,718-sec run was at its minimum value are shown in Plate 15.

Test results conducted with asymmetrical gate openings were compared with previous test results obtained with symmetrical gate openings. Flow patterns and turbulence generated by the asymmetrical gate openings did not increase the magnitude of the pulsating forces acting on the spillway chute and stilling basin.

4 Summary and Discussion of Results

Initially, tests were conducted to ensure that the frequency response of the submerged chute and stilling basin did not influence the measurement of the pressure pulsations by transducers. Also, test data were simultaneously collected by 30 transducers at various sampling rates and for various periods of time to determine the best sampling duration and rate for measuring the pulsating pressures.

Due to the symmetry of the spillway geometry and hydraulic conditions, it was considered that the exciting hydraulic forces would be symmetrical about the longitudinal center line of the spillway. Therefore, the 30 transducers were located on one side of the longitudinal center line. Pressure pulsations were measured with eight anticipated flow conditions. The maximum pulsations occurred with the maximum anticipated discharge of 65,000 cfs. With the center line of the transducers located on a 10-ft grid, the time-history plots indicated no correlation between the pressure pulsations. Some of the transducers were relocated on a 2.5-ft-square grid to increase their density in turbulent areas. Analysis of the time-history and pressure contour plots indicated that there may be some correlation among the pressure pulses measured by the transducers located on the 2.5-ft-square grid.

Tests were also conducted to determine if the pressure pulsations would increase with asymmetrical spillway flow. The asymmetrical flow was generated by uneven spillway gate openings. Some transducers were relocated (type 3 transducer pattern) in turbulent areas as defined by the flow pattern generated by asymmetrical flow. The magnitude and frequency of the pulsating forces were not increased by flow through the asymmetrical spillway gate openings.

The information provided in this report provides, for various flow conditions, the frequency, magnitude, and areal extent of the hydraulic dynamic pressure pulsations acting on the upper surface of the spillway chute and stilling basin apron. These pressure measurements can be used to compute forces acting on various areas of the chute and basin apron. These forces can then be used to evaluate the safety of the structure and to make structural improvements as necessary.

Table 1
Type 1 Transducer Pattern Hydraulic Conditions

Test No.	Upper Pool El	Gate Opening, ft	Discharge, cfs	Lower Pool El
1	1277	Full	65,000	1258.5
2	1267	4	10,400	1237.5
3	1271	7	19,600	1242.0
4	1271	9	24,600	1243.5
5	1276	9	28,000	1254.0
6	1271	12	33,000	1245.0
7	1277	12	52,500	1255.5
8	1271	Full	43,100	1247.2
9	1277	Full	65,000	1258.5
10	1271	Full	43,100	1247.2

Table 2
Pressure Pulsations, Test 1

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
1	10.8	14.9	22.7
2	10.5	14.4	21.4
3	12.2	16.1	23.2
4	13.1	17.3	25.7
5	9.4	17.8	26.5
6	9.5	17.6	37.0
7	13.3	21.0	32.6
8	11.2	20.3	31.0
9	9.4	21.0	29.7
10	10.6	21.6	36.3
11	10.7	23.8	34.2
12	12.2	23.8	32.3
13	6.8	23.6	42.0
14	2.1	26.8	38.9
15	15.4	26.9	39.1
16	13.7	26.5	34.9
17	5.0	26.2	39.1
18	18.4	30.0	39.5
19	20.5	30.5	37.4
20	-4.5	29.9	38.8
21	0.5	34.9	41.0
22	19.8	36.4	42.2
23	14.2	35.7	40.0
24	10.1	35.2	42.8
25	23.7	40.1	45.7
26	21.2	39.6	46.4
27	14.0	38.6	45.2
28	21.2	30.9	38.9
29	20.6	30.1	38.1
30	19.8	30.0	38.8

Note: For discharge, pool elevations, and gate opening, see Table 1

Table 3
Pressure Pulsations, Test 2

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
1	1.0	1.6	2.2
2	1.2	1.7	2.3
3	0.8	1.2	2.0
4	0.5	1.0	1.6
5	0.0	0.9	3.2
6	1.2	1.6	2.6
7	1.4	2.7	13.7
8	0.7	2.1	10.0
9	-3.0	2.0	17.2
10	1.1	3.2	14.0
11	-0.8	5.6	18.3
12	-4.3	4.0	17.5
13	-5.4	5.2	21.5
14	-2.1	8.1	20.4
15	-7.2	7.2	20.2
16	-5.2	7.8	15.3
17	-3.6	7.5	19.7
18	-0.9	10.6	18.4
19	0.1	11.5	16.8
20	-4.6	10.8	19.0
21	-3.5	13.4	19.6
22	-2.1	13.8	19.2
23	5.4	13.5	16.7
24	0.8	13.6	19.4
25	6.0	17.0	21.1
26	7.1	14.8	17.2
27	5.2	15.1	19.3
28	6.5	14.6	18.0
29	5.3	14.7	17.5
30	12.3	15.4	16.7

Note: For discharge, pool elevations, and gate opening, see Table 1.

Table 4
Pressure Pulsations, Test 3

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
1	1.1	2.9	3.7
2	1.7	2.7	3.8
3	1.5	2.3	3.4
4	1.0	2.2	3.9
5	0.8	2.2	8.8
6	-0.6	2.6	4.7
7	3.2	5.5	13.9
8	1.0	4.4	18.1
9	-1.7	3.4	15.9
10	-4.9	5.3	14.2
11	1.3	7.6	19.9
12	-4.1	6.9	23.3
13	-2.4	6.9	23.5
14	-0.7	10.4	24.5
15	-10.2	10.0	25.1
16	-5.5	9.2	22.7
17	-5.1	9.5	31.3
18	0.4	12.8	25.5
19	0.8	12.4	20.7
20	-16.1	11.7	28.2
21	-2.9	16.6	30.2
22	1.6	16.3	24.9
23	3.4	16.0	23.8
24	-11.0	16.0	27.4
25	2.3	22.1	29.2
26	1.6	19.8	25.9
27	-3.8	20.0	27.7
28	7.3	18.1	23.4
29	-1.7	17.4	23.9
30	10.4	18.3	23.9

Note: For discharge, pool elevations, and gate opening, see Table 1.

Table 5
Pressure Pulsations, Test 4

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
1	3.1	3.8	4.7
2	2.6	3.3	4.1
3	0.5	2.9	3.9
4	2.9	3.9	5.8
5	0.9	3.0	10.8
6	2.7	3.4	6.1
7	3.8	7.0	19.7
8	0.6	5.4	18.2
9	1.1	4.5	15.7
10	4.1	6.4	15.1
11	4.0	9.1	20.7
12	-2.6	8.5	24.4
13	1.1	7.9	25.3
14	1.0	12.1	29.9
15	-3.5	11.2	26.7
16	-1.0	11.1	21.3
17	-5.9	10.6	30.7
18	1.8	14.8	27.1
19	2.1	13.9	26.0
20	-3.4	13.1	29.9
21	2.5	18.7	29.6
22	-3.6	18.6	28.4
23	1.4	17.7	24.5
24	-2.6	17.6	29.9
25	3.9	24.2	31.6
26	4.5	22.2	29.0
27	1.4	22.5	30.5
28	3.0	19.6	26.4
29	-3.5	18.8	25.7
30	8.4	19.2	27.1

Note: For discharge, pool elevations, and gate opening, see Table 1.

Table 6
Pressure Pulsations, Test 5

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
1	4.6	16.4	32.4
2	-0.5	15.7	27.0
3	-10.5	16.0	29.4
4	-1.3	18.6	29.9
5	-0.0	18.4	27.1
6	2.1	18.5	28.1
7	7.6	21.1	31.3
8	-1.9	21.2	29.9
9	8.3	21.2	28.8
10	5.4	21.6	31.3
11	10.2	23.2	31.0
12	12.6	23.4	30.1
13	6.4	23.2	31.4
14	9.6	25.5	33.0
15	13.4	25.6	35.2
16	13.2	25.6	31.1
17	10.3	25.0	32.6
18	17.0	27.7	33.9
19	21.2	27.8	33.7
20	16.4	27.6	34.0
21	17.4	30.6	36.3
22	18.0	30.6	35.0
23	21.0	29.5	34.4
24	16.1	30.5	37.4
25	19.0	32.9	37.5
26	23.3	31.2	35.2
27	21.0	31.9	36.5
28	23.3	29.8	34.3
29	21.6	30.4	35.8
30	23.4	30.9	33.5

Note: For discharge, pool elevations, and gate opening, see Table 1.

Table 7
Pressure Pulsations, Test 6

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
1	4.2	4.9	5.8
2	3.5	4.3	5.4
3	2.8	3.7	4.9
4	3.7	4.5	5.6
5	2.3	3.6	5.4
6	3.6	4.3	5.3
7	4.5	5.7	8.5
8	3.2	4.8	9.2
9	1.4	4.3	10.0
10	4.7	6.0	9.2
11	5.0	7.8	17.4
12	2.5	7.3	17.4
13	3.6	6.7	17.6
14	4.5	10.4	24.7
15	-0.4	9.7	27.8
16	2.7	9.3	18.8
17	-3.2	9.2	31.4
18	1.3	13.3	29.0
19	0.1	12.7	24.7
20	-2.7	11.9	30.3
21	2.6	19.5	30.2
22	-3.6	18.6	29.1
23	-4.9	18.1	24.6
24	-1.4	16.9	31.0
25	-6.7	25.1	34.8
26	-0.0	25.5	33.7
27	-1.8	23.5	36.3
28	6.3	18.2	28.5
29	1.7	17.9	26.5
30	4.2	17.5	26.8

Note: For discharge, pool elevations, and gate opening, see Table 1.

Table 8
Pressure Pulsations, Test 7

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
1	4.8	16.6	27.0
2	3.6	16.0	30.8
3	-8.7	16.5	31.3
4	5.8	19.1	32.0
5	-7.7	18.7	29.5
6	2.3	19.1	33.4
7	5.9	21.9	33.4
8	4.3	21.7	32.2
9	0.0	21.7	31.9
10	4.8	22.3	40.5
11	10.3	24.1	37.9
12	6.7	23.9	31.9
13	5.9	23.8	33.7
14	0.4	26.3	36.1
15	8.6	26.4	34.9
16	8.1	26.3	33.4
17	7.9	25.7	35.4
18	14.7	28.8	37.1
19	18.3	28.8	33.8
20	12.6	28.9	35.8
21	12.8	32.3	38.0
22	13.6	32.3	39.1
23	20.5	31.0	37.1
24	15.6	32.4	39.0
25	21.1	35.3	41.0
26	23.6	33.0	38.5
27	14.5	33.9	40.2
28	23.0	30.7	37.9
29	19.2	31.3	37.0
30	22.5	31.6	36.0

Note: For discharge, pool elevations, and gate opening, see Table 1.

Table 9
Pressure Pulsations, Test 8

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
1	5.5	6.4	7.1
2	5.1	6.1	7.1
3	4.9	6.1	8.8
4	5.1	6.2	7.2
5	1.6	5.6	8.0
6	4.8	5.7	6.6
7	5.6	6.8	8.8
8	4.5	5.9	8.8
9	3.2	6.2	10.8
10	6.2	7.4	9.7
11	6.3	8.5	14.0
12	5.7	8.5	14.4
13	5.2	7.6	13.7
14	7.2	11.1	20.9
15	4.1	10.8	23.4
16	7.7	10.6	15.5
17	2.1	10.0	30.2
18	4.1	14.6	29.9
19	2.8	14.5	26.4
20	0.3	13.1	29.4
21	11.0	21.8	29.8
22	3.2	21.6	33.7
23	11.1	21.7	26.6
24	-0.4	18.9	32.8
25	2.8	27.7	38.5
26	-0.8	28.3	35.9
27	-10.1	26.3	37.3
28	9.1	18.7	28.5
29	6.2	18.0	28.2
30	1.1	17.7	28.0

Note: For discharge, pool elevations, and gate opening, see Table 1.

Table 10
Type 2 Transducer Pattern, Hydraulic Conditions

Test No.	Upper Pool El	Gate Opening, ft	Discharge, cfs	Lower Pool El
11	1277	Full	65,000	1258.5
12	1267	4	10,400	1237.5
13	1271	7	19,600	1242.0
14	1271	9	24,600	1243.5
15	1276	9	28,000	1254.0
16	1271	12	33,000	1245.0
17	1277	12	52,500	1255.5
18	1271	Full	43,100	1247.2

Table 11
Pressure Pulsations, Type 2 Transducer Pattern, Test 11

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
13	8.8	23.9	39.8
14	-17.4	27.3	36.7
15	11.2	26.9	39.9
16	8.8	26.9	37.2
17	6.9	26.2	38.5
18	13.7	30.0	39.8
19	8.2	30.9	36.4
20	15.0	30.1	39.6
21	-17.3	35.6	42.2
22	9.0	36.7	42.6
23	9.2	35.4	40.5
24	14.2	35.5	41.4
25	20.0	40.2	46.5
26	19.8	40.0	46.3
27	-0.0	38.8	46.8
31	22.4	37.0	43.1
32	10.4	34.4	40.1
33	17.8	38.2	43.4
34	6.0	35.0	40.2
35	-4.1	32.4	40.4
36	-13.2	34.5	41.9
37	-3.5	37.9	43.7
38	3.2	35.2	41.5
39	-5.5	32.6	40.8
40	2.2	35.4	41.9
41	9.1	32.9	40.6
42	12.6	27.7	37.8
43	15.2	30.0	38.6
44	12.8	30.0	39.7
45	13.1	32.2	37.2

Note: For discharge, pool elevations, and gate opening, see Table 10.

Table 12
Pressure Pulsations, Type 2 Transducer Pattern, Test 12

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
13	-4.3	4.4	19.6
14	-2.4	6.8	17.7
15	-4.6	5.8	19.3
16	-4.4	6.4	16.3
17	-4.7	6.2	21.5
18	-5.0	9.2	19.7
19	-2.3	10.2	17.8
20	-8.0	9.7	21.1
21	-2.2	13.5	19.8
22	1.6	12.8	19.0
23	-0.5	12.6	16.2
24	1.2	12.7	19.5
25	5.0	16.5	22.0
26	4.2	14.4	17.9
27	4.3	14.5	23.5
31	2.1	13.6	21.4
32	1.0	12.2	21.2
33	-0.4	14.5	21.4
34	1.1	12.8	19.4
35	-0.0	11.1	18.1
36	-0.6	12.6	20.4
37	-7.9	14.5	21.6
38	-3.7	12.8	20.8
39	-3.8	11.8	20.2
40	-0.9	13.0	19.3
41	3.4	12.8	17.8
42	-6.7	6.7	21.7
43	-4.3	9.6	18.2
44	-5.9	9.6	23.2
45	-2.2	11.1	20.5

Note: For discharge, pool elevations, and gate opening, see Table 10.

Table 13
Pressure Pulsations, Type 2 Transducer Pattern, Test 13

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
13	-0.9	6.8	25.2
14	0.5	10.4	26.9
15	-4.9	9.1	30.2
16	-3.0	8.7	19.4
17	-7.9	9.0	30.2
18	0.0	12.5	27.6
19	0.6	12.2	22.0
20	-5.3	11.9	28.7
21	-3.8	16.9	28.7
22	2.7	16.0	25.3
23	0.1	15.5	22.6
24	-8.2	15.9	29.5
25	3.5	22.0	30.4
26	4.4	20.5	27.1
27	-1.9	19.9	29.3
31	-1.0	17.1	31.0
32	0.8	16.1	26.3
33	-14.5	19.6	28.7
34	-0.2	16.8	27.1
35	-0.6	14.7	29.4
36	-3.9	16.4	28.5
37	0.6	18.8	30.4
38	-5.5	16.9	28.9
39	-2.5	15.0	25.7
40	-3.2	17.3	28.4
41	-11.1	15.9	24.2
42	-9.8	10.5	30.4
43	-5.7	11.2	25.9
44	-7.8	12.3	29.8
45	-4.8	13.5	26.9

Note: For discharge, pool elevations, and gate opening, see Table 10.

Table 14
Pressure Pulsations, Type 2 Transducer Pattern, Test 14

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
13	0.8	7.4	24.7
14	1.2	11.6	28.1
15	-4.5	10.3	29.4
16	0.5	10.1	21.1
17	-3.8	10.1	31.4
18	-2.5	13.7	27.2
19	-3.7	13.2	24.0
20	-6.1	12.9	30.4
21	1.5	18.5	29.0
22	-6.4	17 4	27.7
23	1.1	17.3	23.8
24	-5.1	16.9	28.8
25	4.3	23.5	32.5
26	2.9	22.6	29.3
27	-6.0	21.9	31.1
31	0.3	18.6	29.4
32	-1.4	17.3	29.3
33	5.1	20.9	29.7
34	4.1	18.3	29.0
35	-2.9	15.9	29.6
36	-7.1	17.8	30.7
37	-0.1	20.6	29.4
38	-4.7	18.4	28.8
39	-13.0	16.3	29.5
40	-15.0	19.0	30.4
41	-6.8	16.9	25.8
42	-5.0	11.4	28.6
43	-8.7	11.6	25.8
44	-3.7	13.2	30.3
45	-12.2	14.4	28.2

Note: For discharge, pool elevations, and gate opening, see Table 10.

Table 15
Pressure Pulsations, Type 2 Transducer Pattern, Test 15

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
13	9.4	22.6	30.6
14	9.3	25.2	32.2
15	11.5	25.2	32.3
16	13.7	25.0	31.7
17	11.3	24.6	32.7
18	9.7	27.0	32.8
19	14.2	27.3	33.9
20	15.6	27.2	33.8
21	13.8	30.2	35.9
22	19.8	29.8	35.0
23	20.2	29.2	33.5
24	19.6	30.3	35.4
25	17.7	32.1	36.7
26	20.8	31.0	36.0
27	23.3	31.7	38.4
31	17.7	30.6	35.7
32	15.3	29.4	35.7
33	18.4	31.6	35.8
34	18.0	30.0	35.6
35	17.5	28.6	35.4
36	9.2	30.2	36.3
37	15.0	31.6	36.2
38	18.7	30.2	35.4
39	16.2	29.0	36.2
40	16.0	30.6	35.9
41	14.8	29.6	34.1
42	12.7	26.3	35.9
43	13.7	27.2	32.9
44	12.6	27.4	34.9
45	13.2	28.1	34.1

Note: For discharge, pool elevations, and gate opening, see Table 10.

Table 16
Pressure Pulsations, Type 2 Transducer Pattern, Test 16

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
13	3.7	7.0	24.8
14	3.9	11.4	24.0
15	-1.0	10.2	27.4
16	1.9	9.8	20.6
17	-1.8	9.8	33.3
18	0.8	13.7	30.0
19	-0.2	13.4	27.1
20	-1.8	12.6	33.2
21	5.7	20.2	33.0
22	2.2	18.5	29.6
23	0.2	18.3	24.9
24	-11.2	17.3	33.6
25	2.9	25.2	35.3
26	-2.0	26.0	34.6
27	-10.0	23.8	33.9
31	4.9	19.5	32.0
32	2.1	17.8	31.7
33	6.7	22.3	32.0
34	4.2	19.6	30.7
35	1.0	16.3	28.8
36	6.8	18.8	30.2
37	5.9	23.1	32.3
38	-9.1	20.3	31.0
39	-0.9	17.6	30.6
40	-1.9	22.1	30.2
41	-2.4	17.6	27.2
42	-2.8	11.0	30.7
43	-7.8	11.7	28.0
44	-5.5	12.9	32.9
45	-5.0	14.4	32.6

Note: For discharge, pool elevations, and gate opening, see Table 10.

Table 17
Pressure Pulsations, Type 2 Transducer Pattern, Test 17

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
13	5.4	23.7	34.3
14	10.2	26.4	35.4
15	4.9	26.2	34.0
16	10.3	26.0	33.6
17	7.4	25.5	35.9
18	13.8	28.4	35.9
19	20.3	28.7	35.2
20	13.3	28.4	36.4
21	14.2	32.1	39.4
22	15.4	31.9	37.6
23	12.6	30.7	35.9
24	17.4	32.3	38.9
25	20.4	35.4	41.7
26	19.6	33.3	38.9
27	18.1	34.2	40.3
31	12.6	32.9	37.8
32	15.2	31.5	38.4
33	15.4	33.9	39.8
34	16.1	31.7	37.9
35	9.7	30.4	39.9
36	9.3	31.9	40.1
37	9.3	33.9	40.8
38	13.5	32.3	40.3
39	13.3	30.7	37.6
40	15.7	32.4	38.7
41	17.0	31.4	36.9
42	12.4	27.3	35.8
43	12.3	28.9	36.6
44	11.2	28.8	36.3
45	10.8	29.8	37.3

Note: For discharge, pool elevations, and gate opening, see Table 10.

Table 18
Pressure Pulsations, Type 2 Transducer Pattern, Test 18

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
13	3.2	17.5	22.9
14	11.4	19.8	23.8
15	10.5	19.8	24.0
16	13.6	19.8	23.7
17	7.0	19.1	23.2
18	12.6	21.1	25.4
19	15.2	21.4	25.1
20	11.8	21.6	25.8
21	14.6	23.1	26.2
22	15.7	23.0	27.8
23	17.3	22.7	25.3
24	17.1	23.8	26.6
25	19.1	23.7	27.9
26	20.5	24.3	28.4
27	18.9	24.9	28.3
31	11.7	23.1	27.1
32	13.1	22.5	25.9
33	15.2	23.6	26.9
34	14.9	22.6	25.8
35	16.0	22.4	26.5
36	14.4	23.1	26.9
37	17.1	24.0	27.7
38	16.4	23.3	26.7
39	15.9	22.6	26.0
40	14.9	23.5	27.0
41	18.6	23.3	25.9
42	13.0	20.7	25.4
43	12.8	20.9	24.0
44	14.3	21.8	25.6
45	15.4	22.4	25.7

Note: For discharge, pool elevations, and gate opening, see Table 10.

Table 19
Type 3 Transducer Pattern, Hydraulic Conditions

Test No.	Pool El	Gate Opening*	Discharge, cfs	Tailwater El
19	1273.2	Gate 1 closed Gates 2 and 3 fully open	36,000	1244.8
20	1279.6	Gate 1 closed Gates 2 and 3 fully open	57,000	1258.5
21	1267.0	Gate 1 closed Gates 2 and 3 fully open	19,500	1241.0

* Gates are numbered from left to right looking downstream.

Table 20
Pressure Pulsations, Type 3 Transducer Pattern, Test 19

Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
46	7.9	9.4	12.6
47	6.3	8.0	11.5
48	8.1	10.4	15.1
49	5.9	8.1	13.2
50	6.2	9.3	15.1
51	6.1	9.5	15.9
52	7.1	11.5	18.9
53	6.4	9.9	21.3
54	7.7	11.2	17.3
55	8.9	13.4	23.2
13	8.2	13.1	20.3
56	7.1	14.5	23.3
15	6.0	13.8	23.6
57	13.0	17.1	23.8
16	12.4	17.8	23.4
17	8.1	17.6	27.5
43	10.1	19.4	29.9
18	8.4	18.2	29.7
19	15.4	21.0	25.0
45	13.2	20.7	27.6
20	11.6	20.0	29.2
42	9.5	20.0	29.7
44	14.2	22.7	31.8
21	7.3	25.5	32.4
22	18.3	27.4	32.7
23	19.3	27.3	31.4
24	10.8	24.4	31.6
25	12.3	31.0	39.2
26	23.4	31.8	36.7
27	13.6	31.5	39.2

Note: For discharge, pool elevations, and gate opening, see Table 19.

Table 21
Pressure Pulsations, Type 3 Transducer Pattern, Test 20

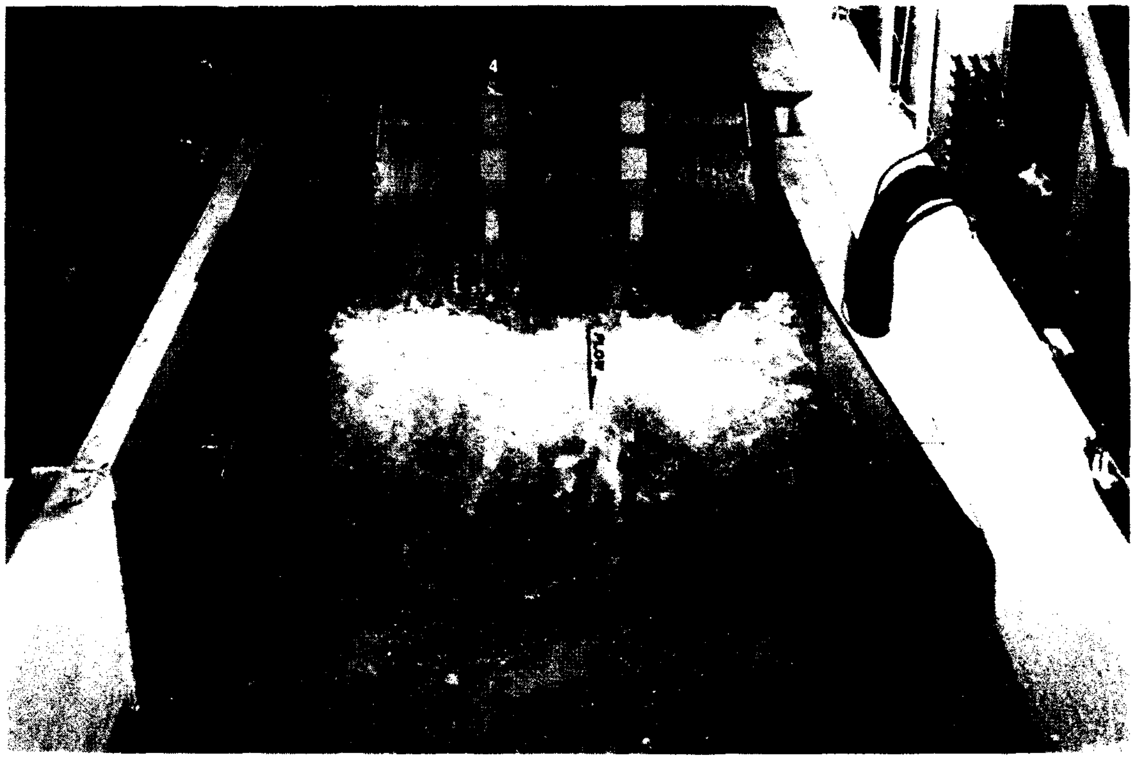
Transducer No.	Pressure, ft of water		
	Minimum	Average	Maximum
46	17.4	20.7	26.5
47	18.8	22.1	28.3
48	18.4	22.8	30.4
49	19.7	24.3	28.4
50	20.9	24.7	29.6
51	19.0	24.2	31.2
52	15.2	24.3	33.3
53	15.5	26.5	34.1
54	20.1	27.1	30.9
55	22.5	27.3	33.3
13	16.8	26.7	35.7
56	12.9	26.5	36.4
15	20.4	29.4	36.7
57	24.0	31.4	35.6
16	24.5	30.7	39.1
17	17.8	29.1	39.2
43	13.2	31.8	41.0
18	22.4	32.6	39.1
19	25.6	34.4	37.5
45	18.4	33.6	40.5
20	19.2	32.3	40.4
42	17.0	32.5	41.5
44	22.7	35.2	43.6
21	12.9	38 3	43.0
22	30.6	39.4	43.2
23	29.7	39.1	42.1
24	17.6	36.7	44.6
25	21.1	42.4	47.7
26	29.5	42.4	47.6
27	17.2	42.2	50.0

Note: For discharge, pool elevations, and gate opening, see Table 19.

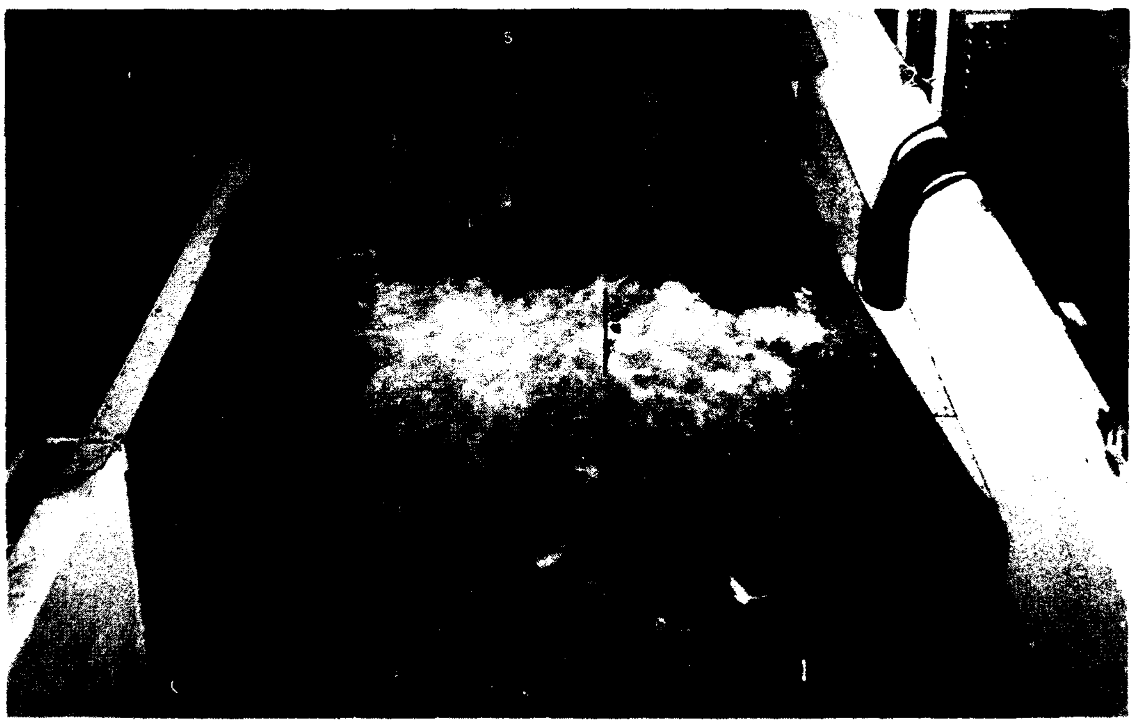
Table 22
Pressure Pulsations, Type 3 Transducer Pattern, Test 21

	Pressure, ft of water		
Transducer No.	Minimum	Average	Maximum
46	4.5	5.6	7.7
47	3.2	4.3	7.1
48	4.8	6.6	13.4
49	-0.3	3.9	10.1
50	1.0	4.7	11.3
51	2.8	5.0	11.8
52	2.9	8.0	16.1
53	2.9	6.9	19.9
54	2.3	6.9	14.3
55	3.0	8.8	18.2
13	1.2	8.4	17.5
56	4.0	10.9	20.9
15	2.9	10.6	22.1
57	5.0	12.8	20.2
16	6.4	13.0	23.9
17	2.5	14.1	23.0
42	5.8	15.0	24.4
18	3.8	14.5	25.9
19	5.6	16.3	23.1
43	5.6	16.0	25.1
20	6.2	15.3	23.3
44	7.7	15.9	24.6
45	-2.8	17.7	24.7
21	-5.6	19.5	27.1
22	2.5	20.0	27.7
23	7.9	21.3	25.5
24	7.4	18.7	25.3
25	3.9	23.7	31.1
26	12.2	25.6	31.4
27	7.1	25.3	32.3

Note: For discharge, pool elevations, and gate opening, see Table 19.

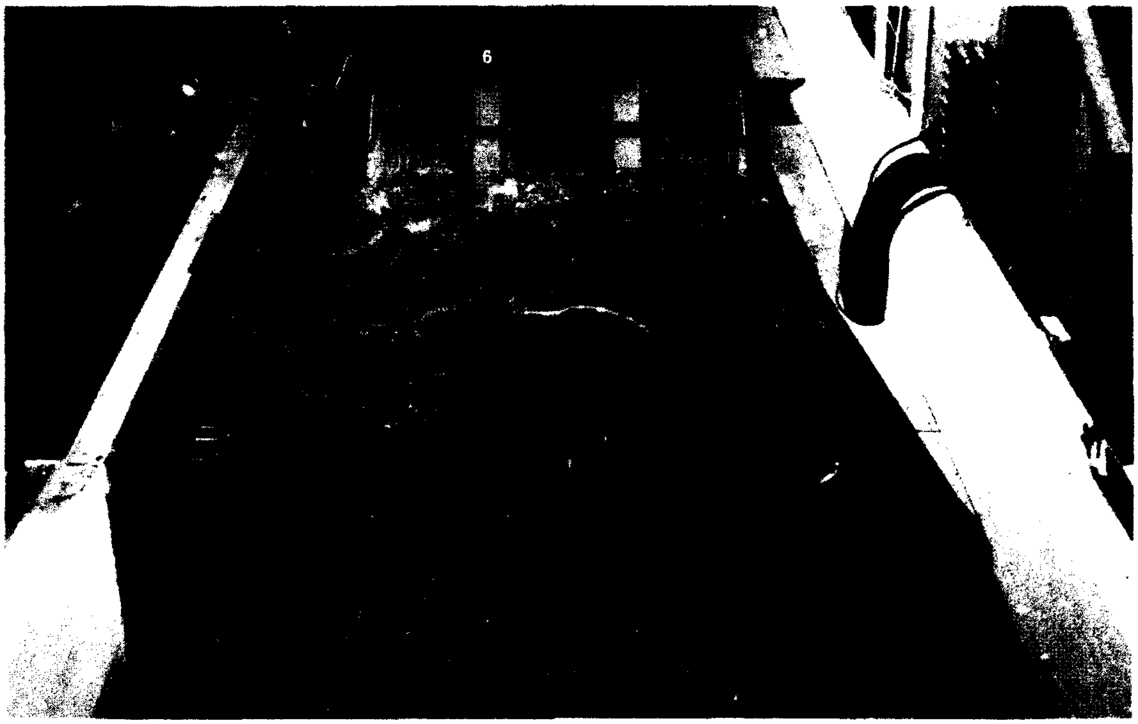


a. Discharge 19,600 cfs, upper pool el 1271.2, lower pool el 1242.0, gate opening 7 ft



b. Discharge 24,600 cfs, upper pool el 1271.1, lower pool el 1243.5, gate opening 9 ft

Photo 1. Anticipated flow conditions (Sheet 1 of 3)



c. Discharge 28,000 cfs, upper pool el 1276.0, lower pool el 1254.0, gate opening 9 ft

d. Discharge 33,000 cfs, upper pool el 1271.1, lower pool el 1245.0, gate opening 12 ft

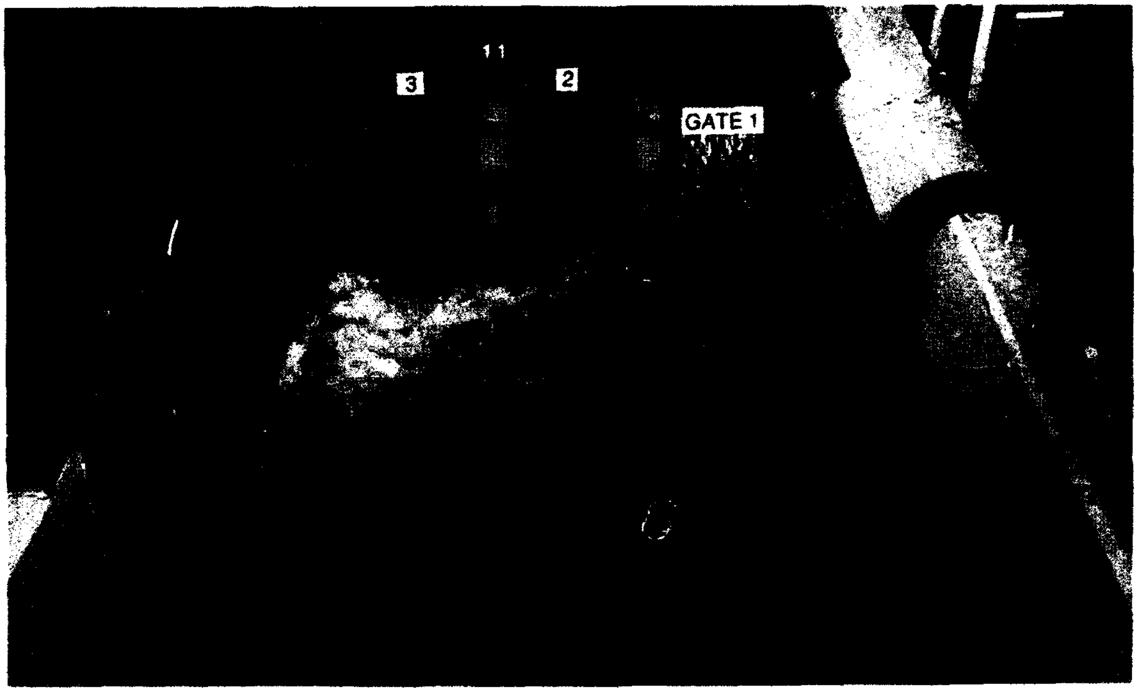
Photo 1. (Sheet 2 of 3)

e. Discharge 52,500 cfs, upper pool el 1277.0, lower pool el 1255.5, gate opening 12 ft

f. Discharge 65,000 cfs, upper pool el 1277.1, lower pool el 1258.5, gate opening fully open

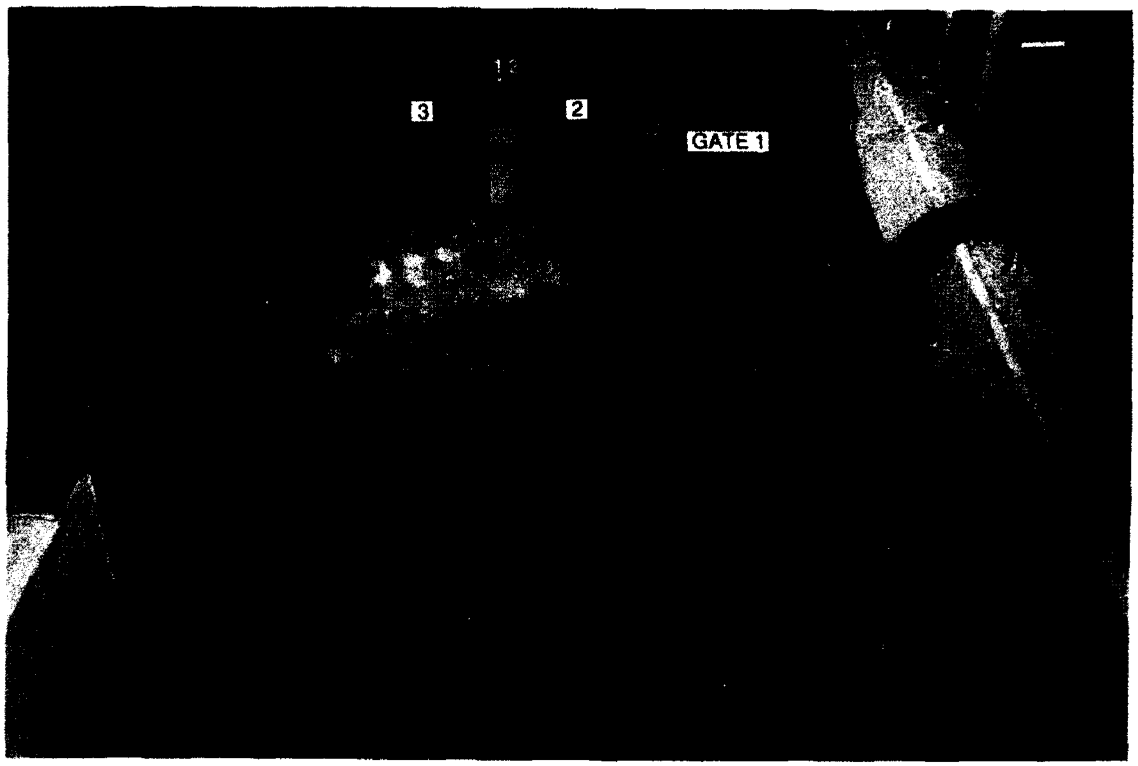
Photo 1. (Sheet 3 of 3)

a. Discharge 18,500 cfs, upper pool el 1267.0, lower pool el 1241.0



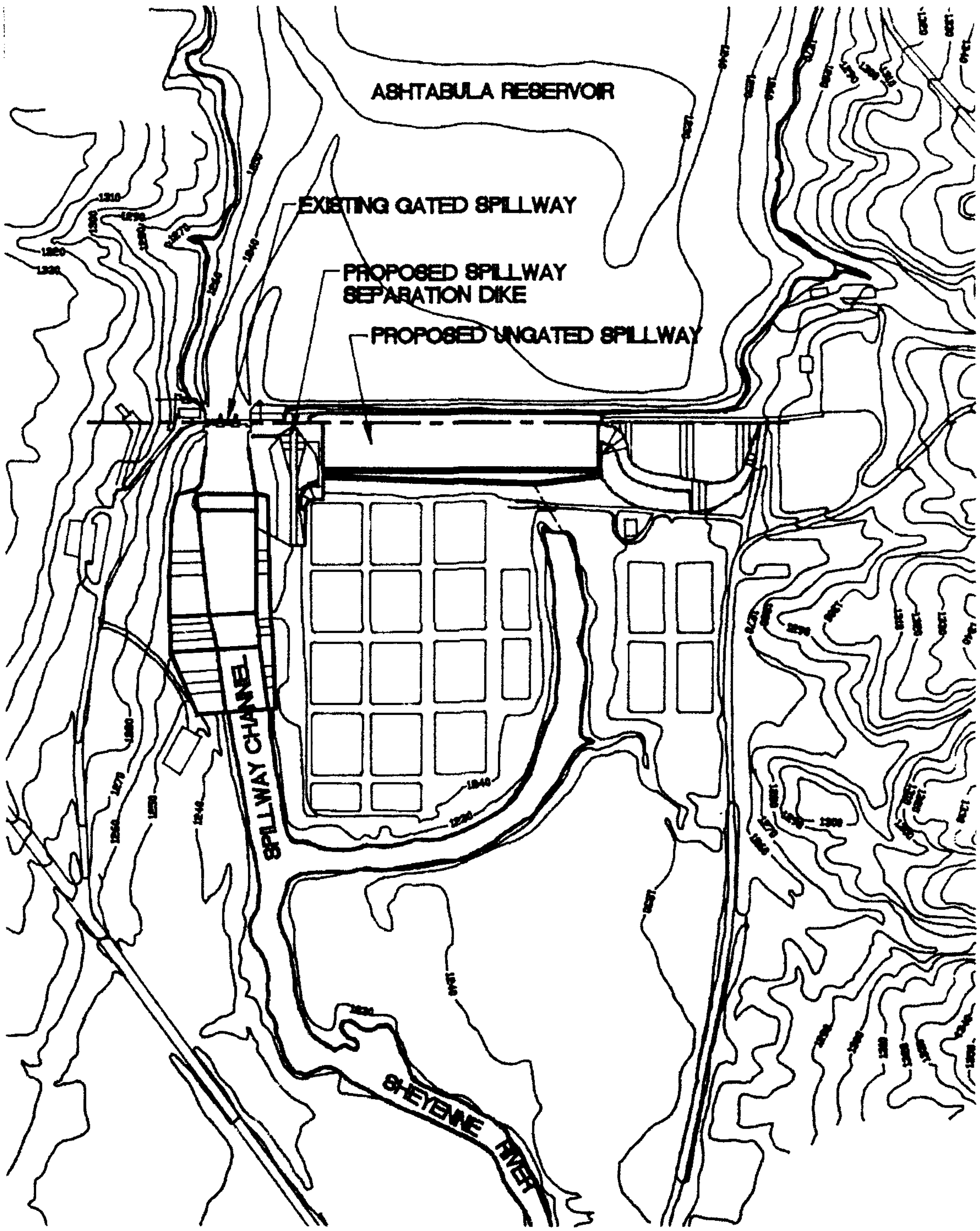
b. Discharge 36,000 cfs, upper pool el 1273.2, lower pool el 1244.8

Photo 2. Asymmetrical flows, gate 1 closed, gates 2 and 3 fully open (Continued)



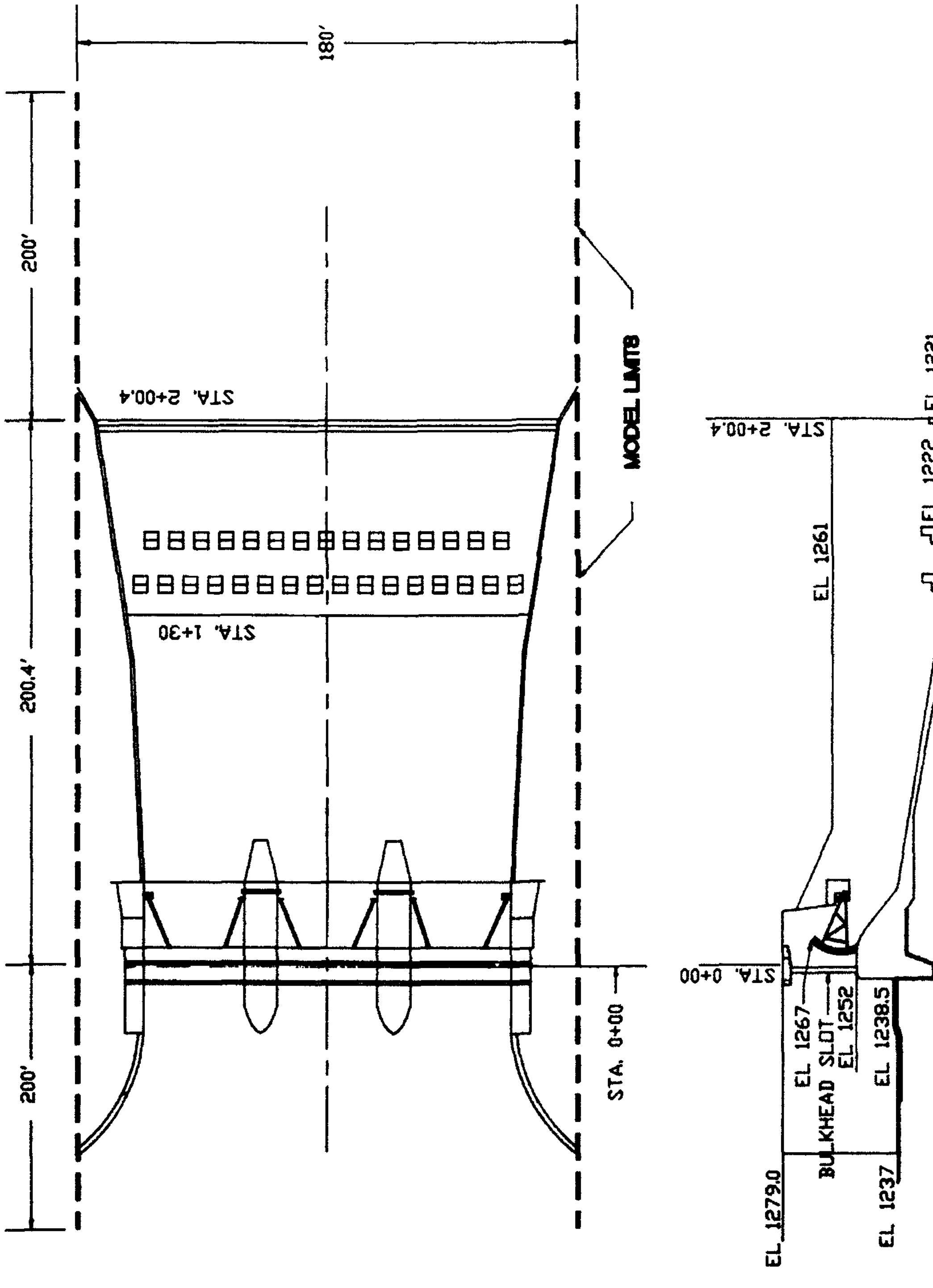
c. Discharge 57,000 cfs, upper pool el 1279.6, lower pool el 1258.5

Photo 2. (Concluded)



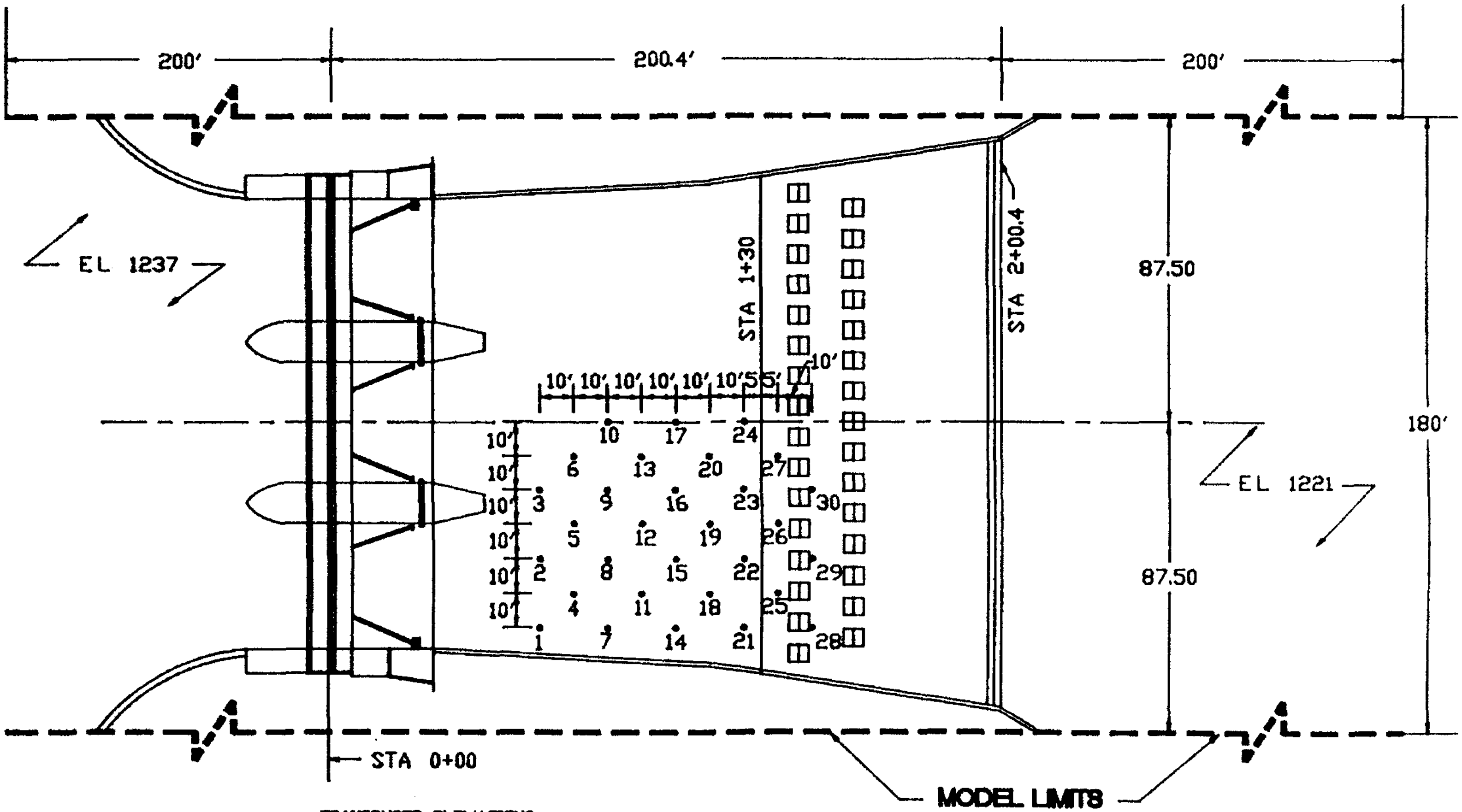
PROJECT PLAN

PLATE 1



SPILLWAY PLAN AND PROFILE

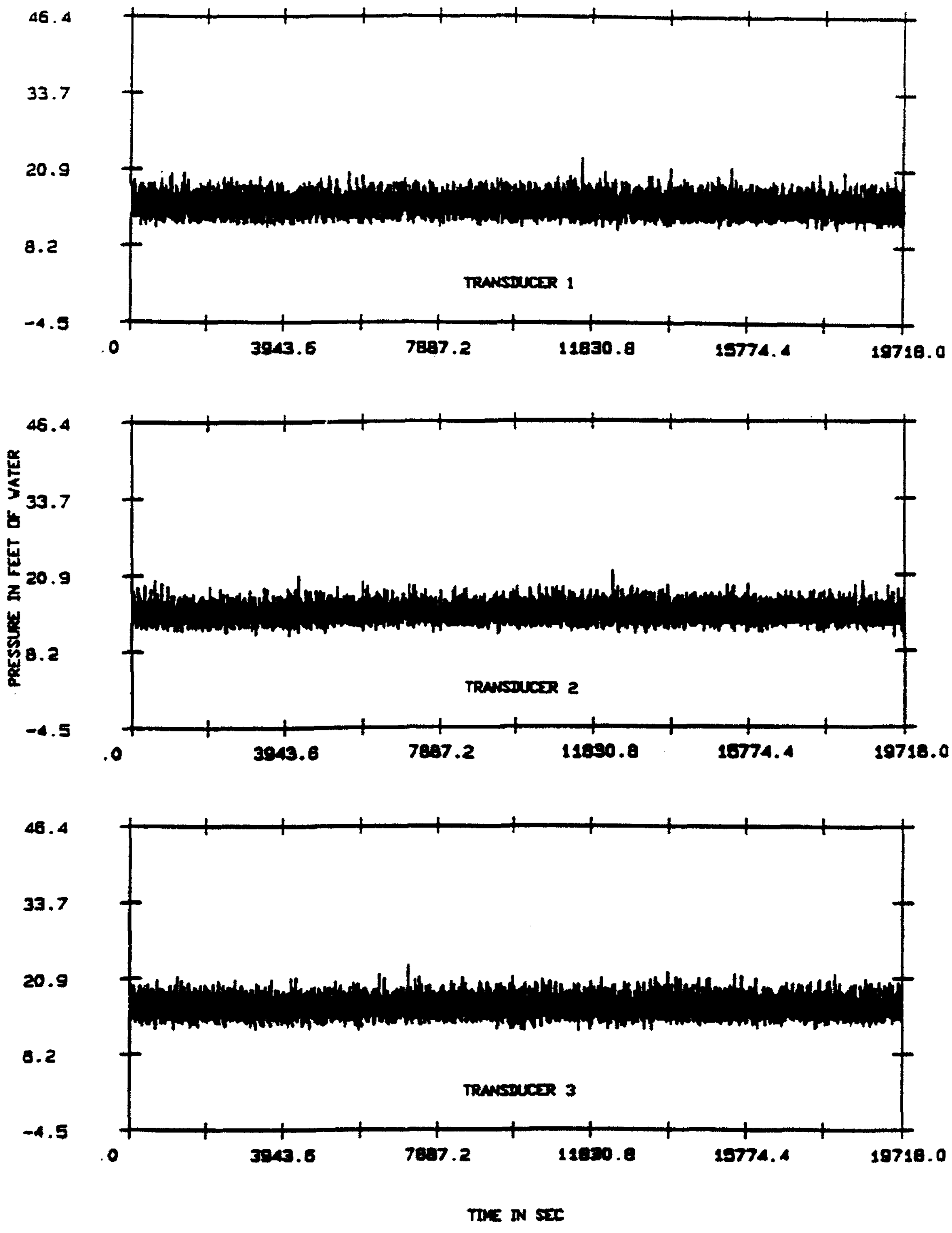
PLATE 2



TRANSDUCER ELEVATIONS

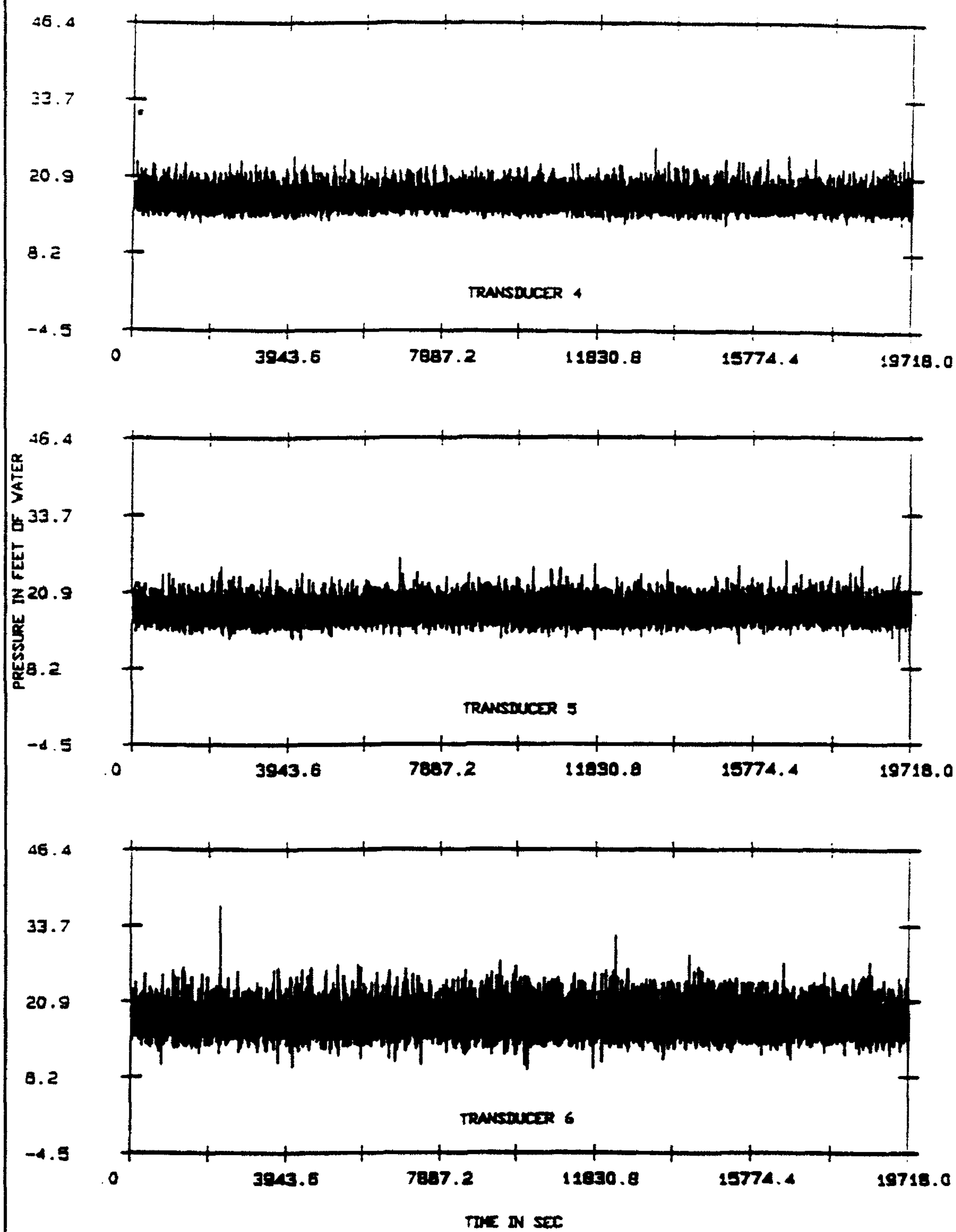
NO.	ELEVATION	NO.	ELEVATION	NO.	ELEVATION	NO.	ELEVATION
1	1231.85	9	1228.82	16	1225.79	24	1222.76
2	1231.85	10	1228.82	17	1225.79	25	1222.00
3	1231.85	11	1227.30	18	1224.27	26	1222.00
4	1230.33	12	1227.30	19	1224.27	27	1222.00
5	1230.33	13	122.730	20	1224.27	28	1222.00
6	1230.33	14	1225.79	21	1222.76	29	1222.00
7	1228.82	15	1225.79	22	1222.76	30	1222.00
8	1228.82			23	1222.76		

TRANSDUCER LOCATIONS
TYPE 1 PATTERN



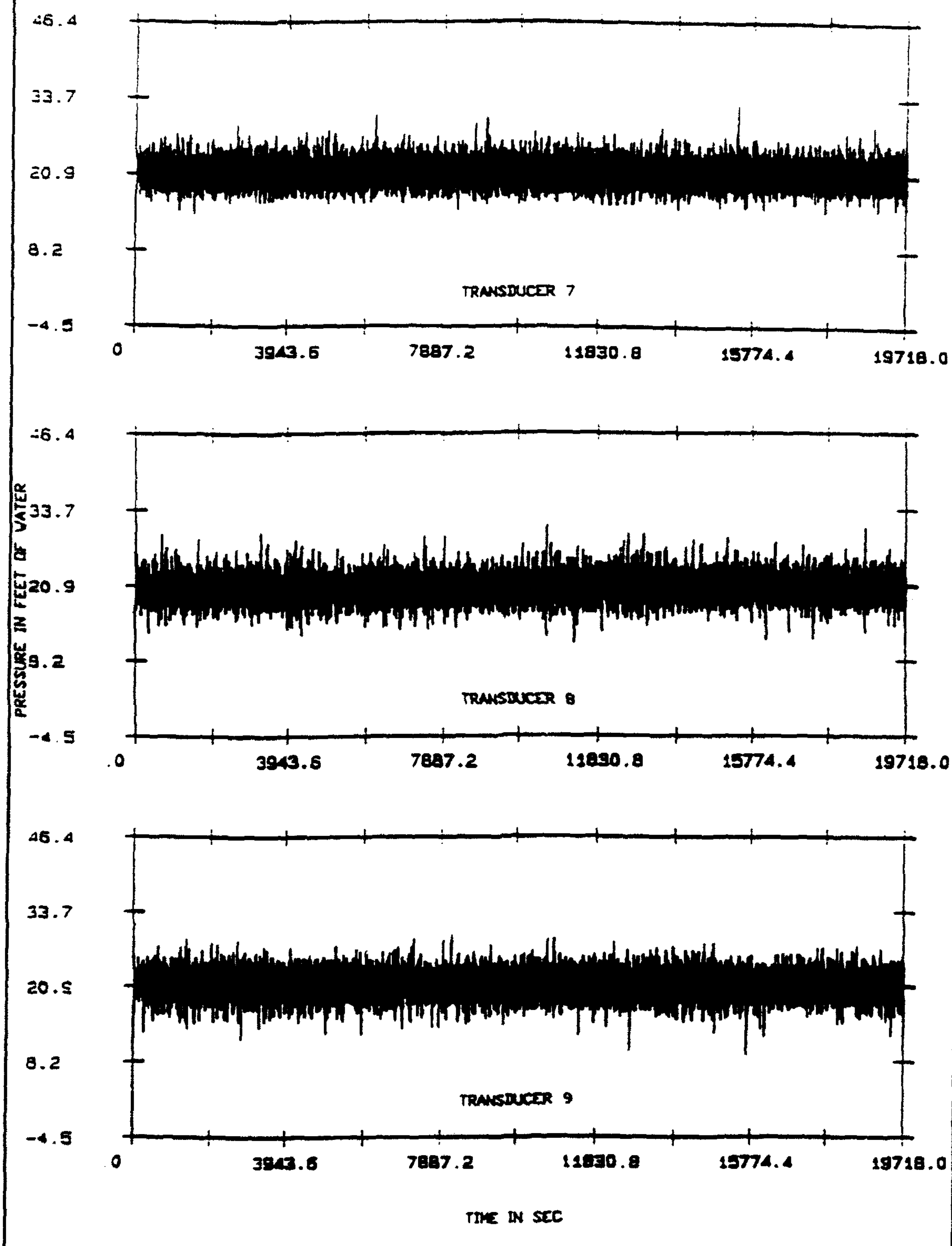
TIME-HISTORY PLOTS
TEST 1

PLATE 4
(Sheet 1 of 10)



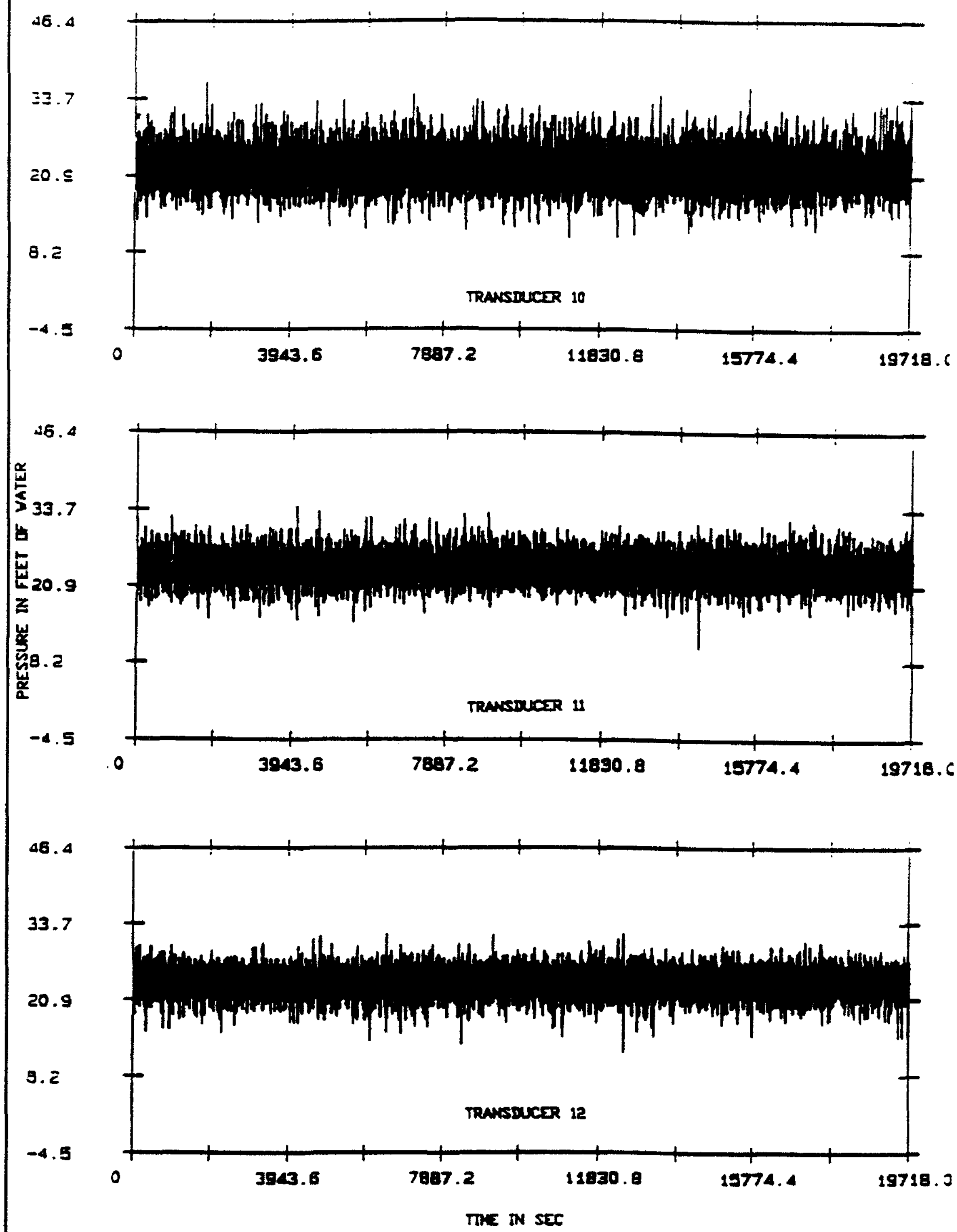
TIME-HISTORY PLOTS
TEST 1

PLATE 4
(Sheet 2 of 10)

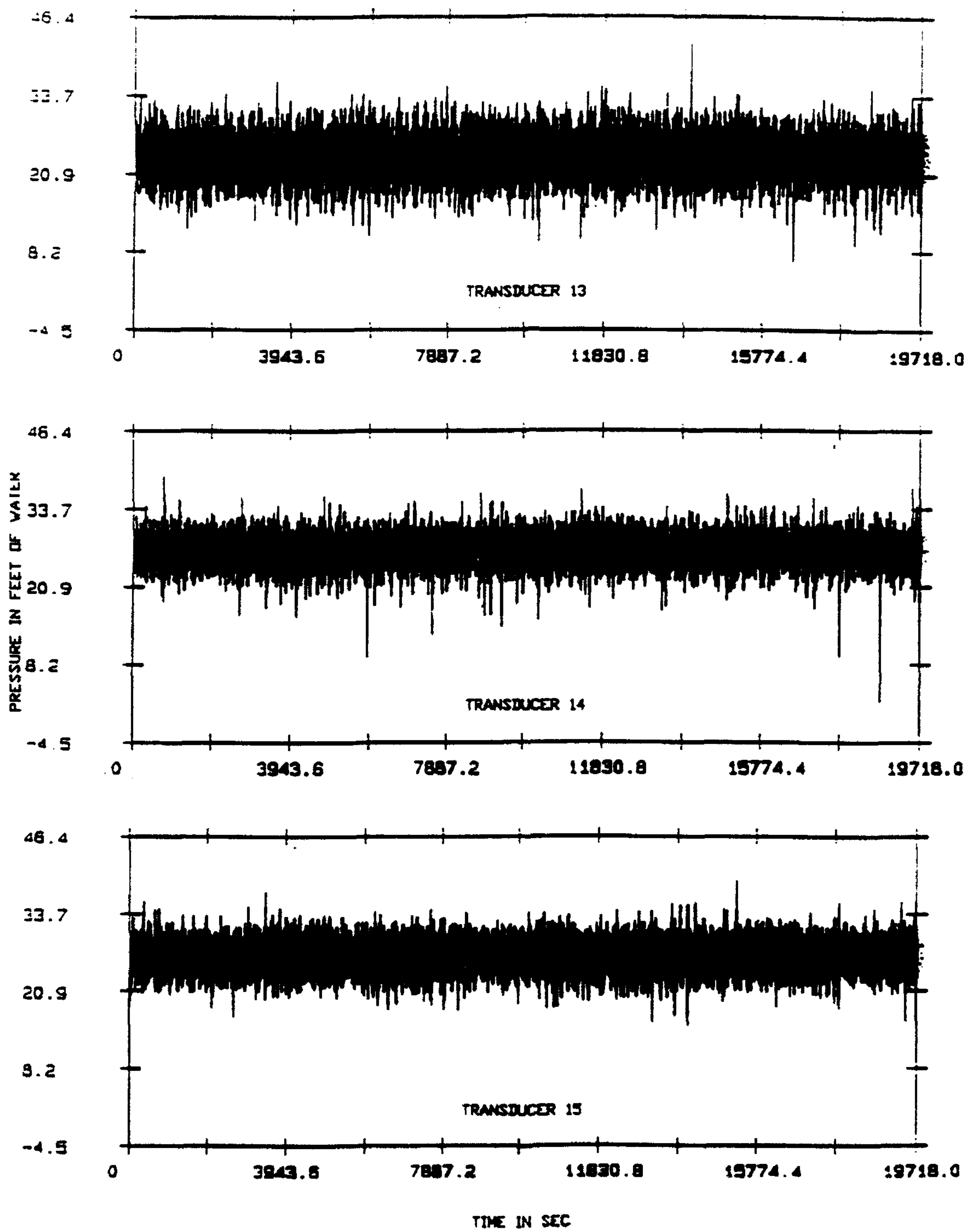


TIME-HISTORY PLOTS
TEST 1

PLATE 4
(Sheet 3 of 10)

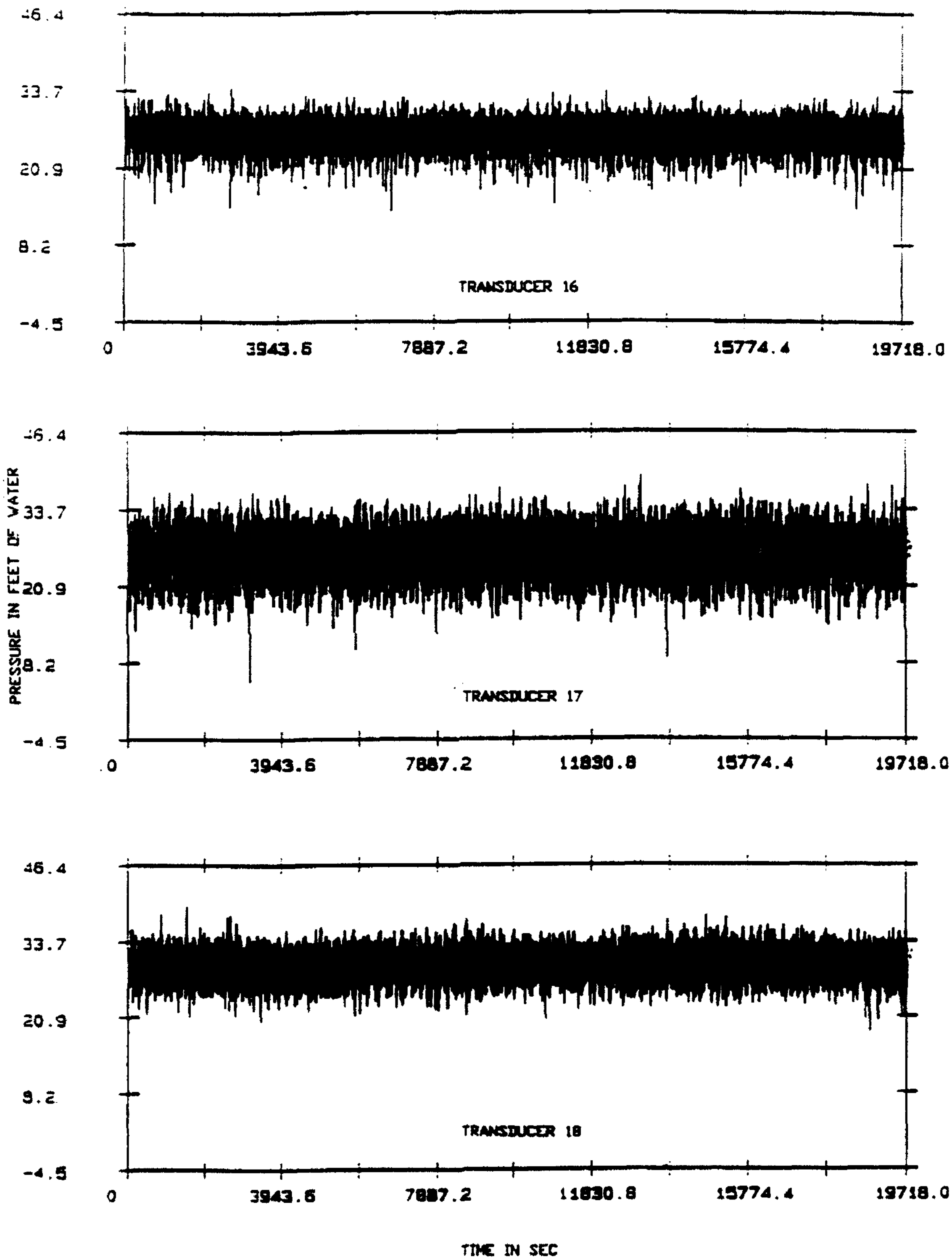


TIME-HISTORY PLOTS
TEST 1



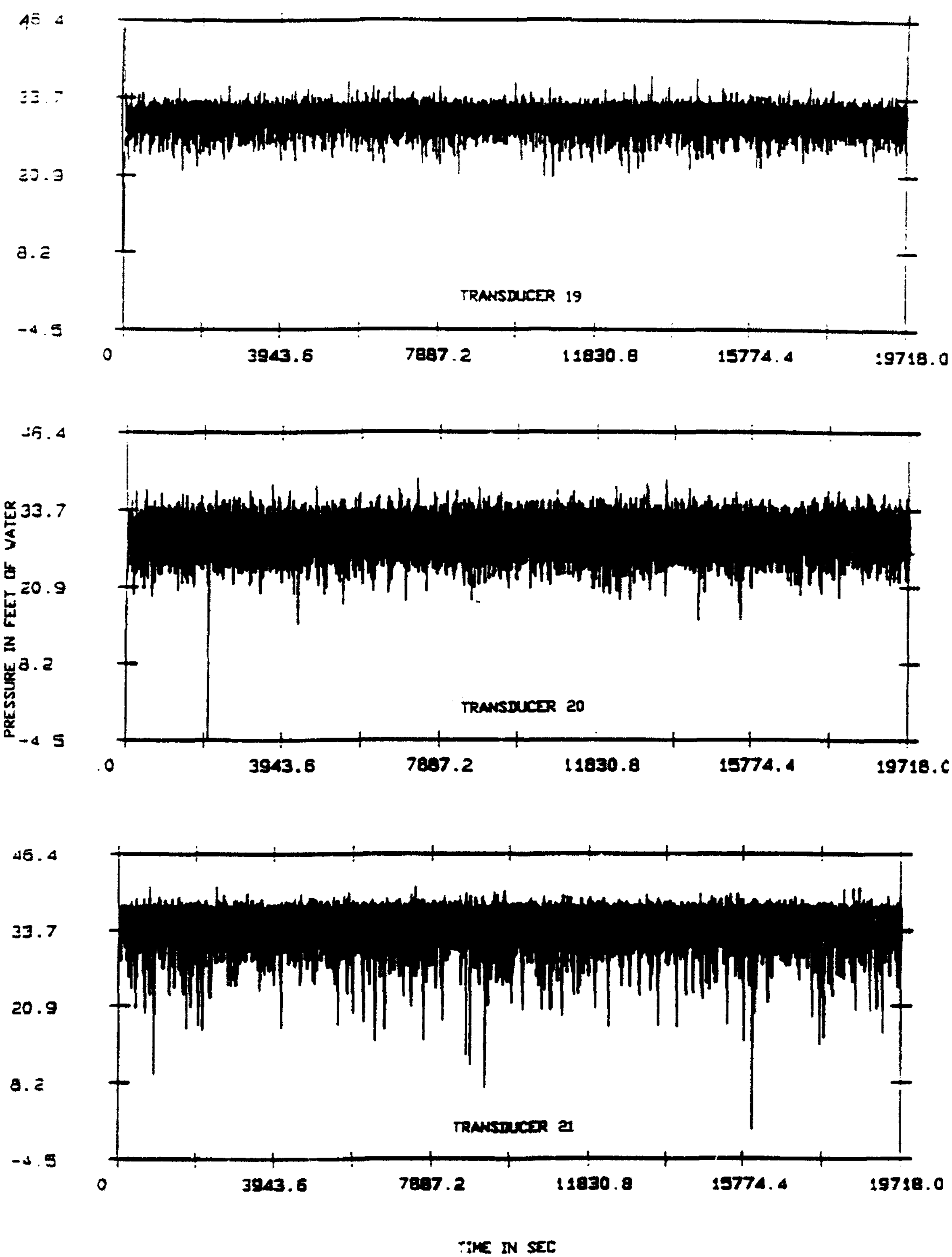
TIME-HISTORY PLOTS
TEST 1

PLATE 4
(Sheet 5 of 10)



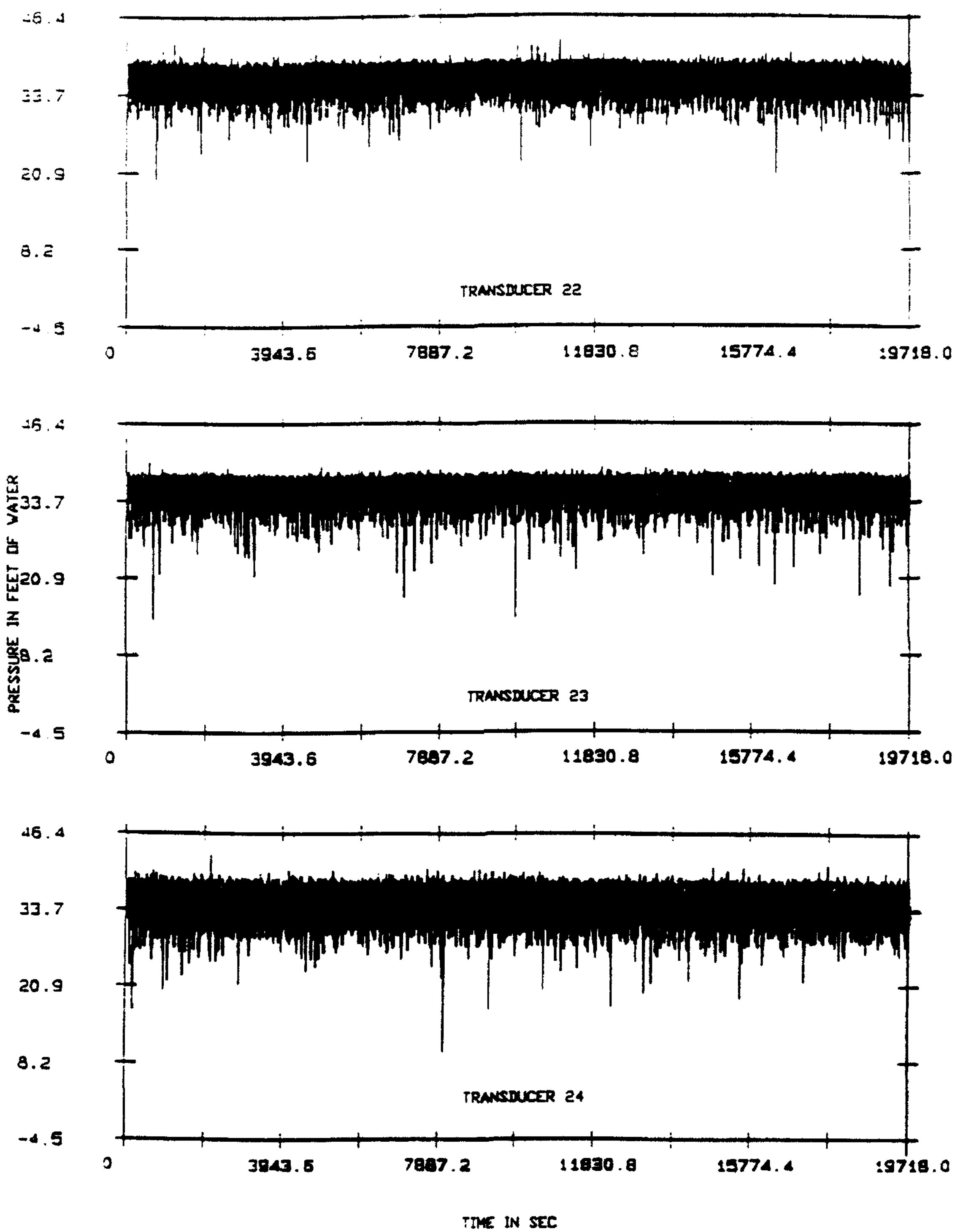
TIME-HISTORY PLOTS
TEST 1

PLATE 4
(Sheet 6 of 10)



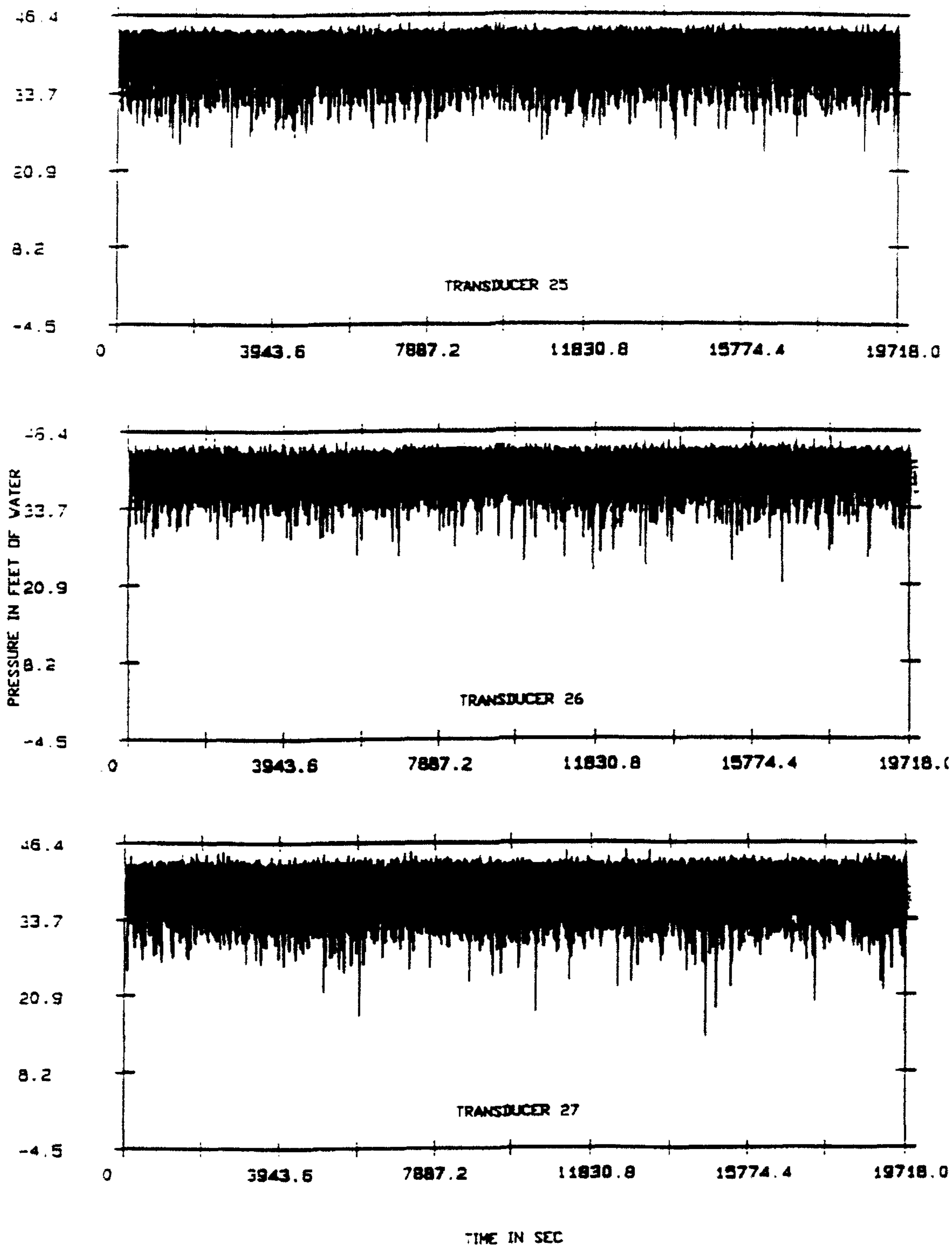
TIME-HISTORY PLOTS
TEST 1

PLATE 4
(Sheet 7 of 10)



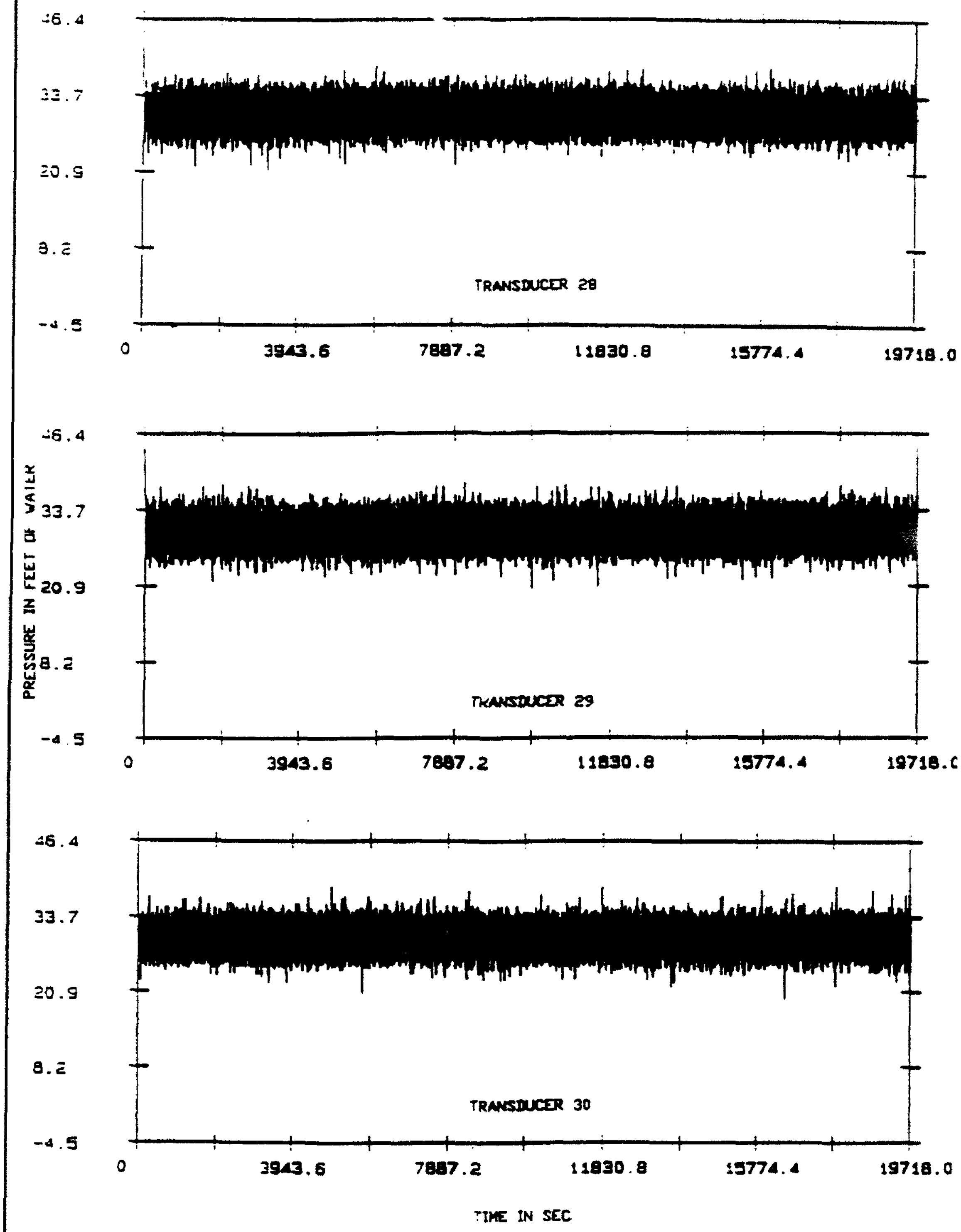
TIME-HISTORY PLOTS
TEST 1

PLATE 4
(Sheet 8 of 10)



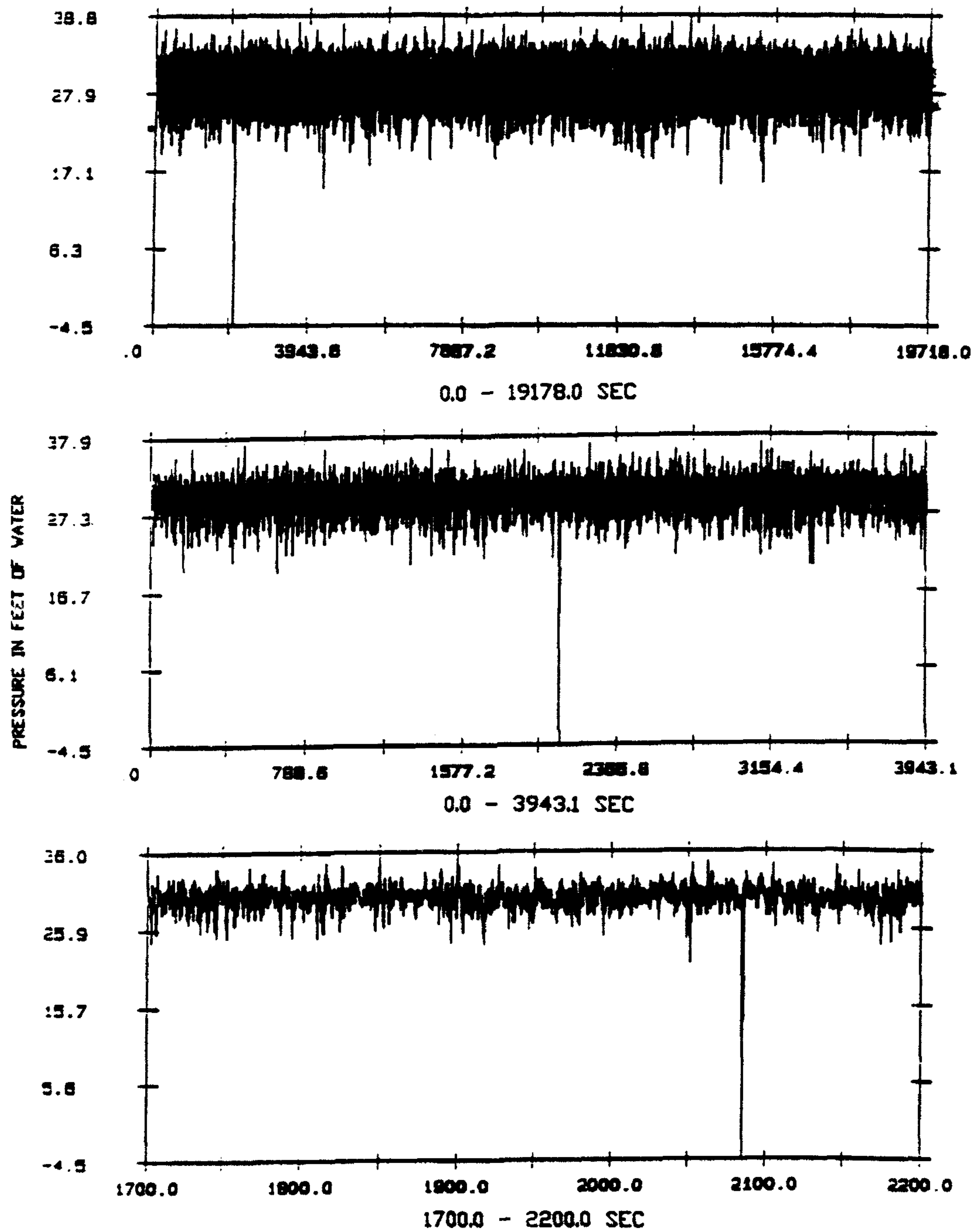
TIME-HISTORY PLOTS
TEST 1

PLATE 4
(Sheet 9 of 10)



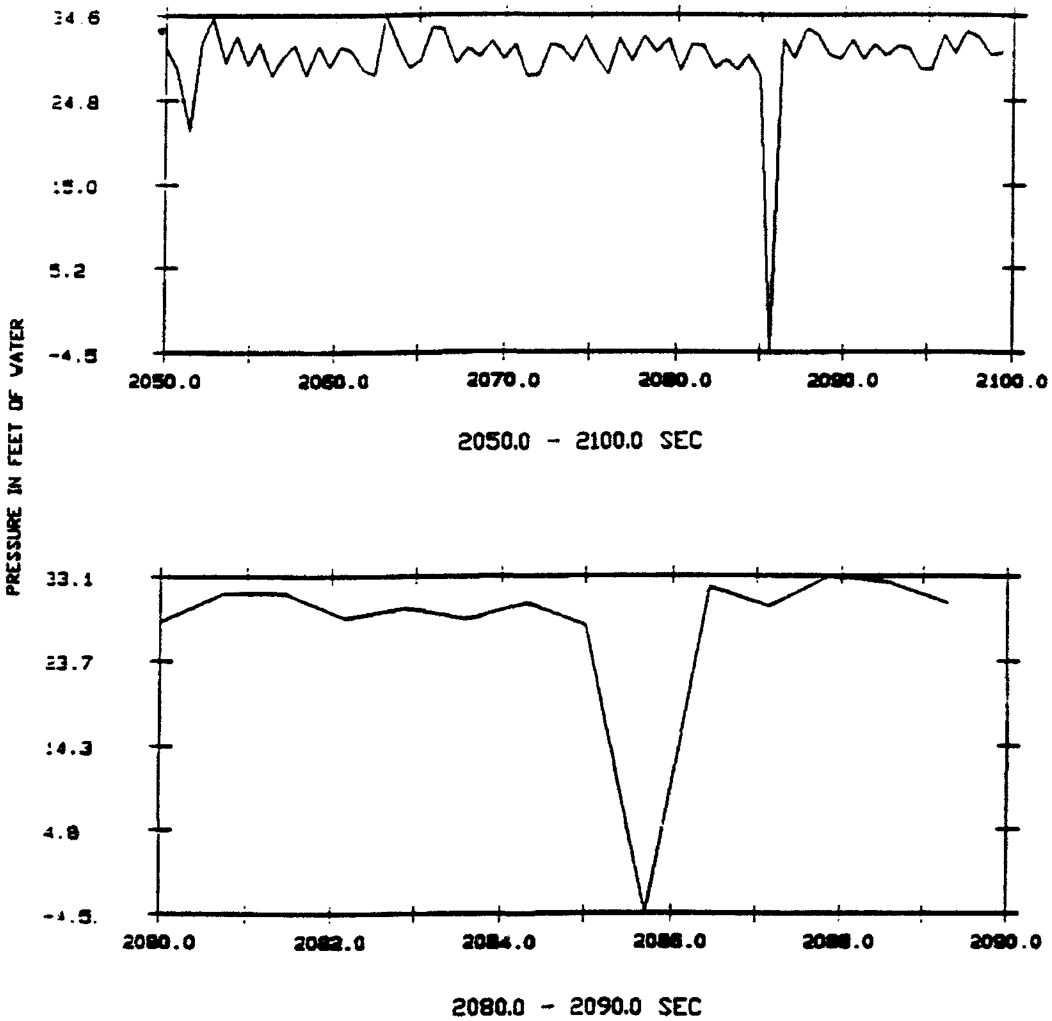
TIME-HISTORY PLOTS
TEST 1

PLATE 4
(Sheet 10 of 10)

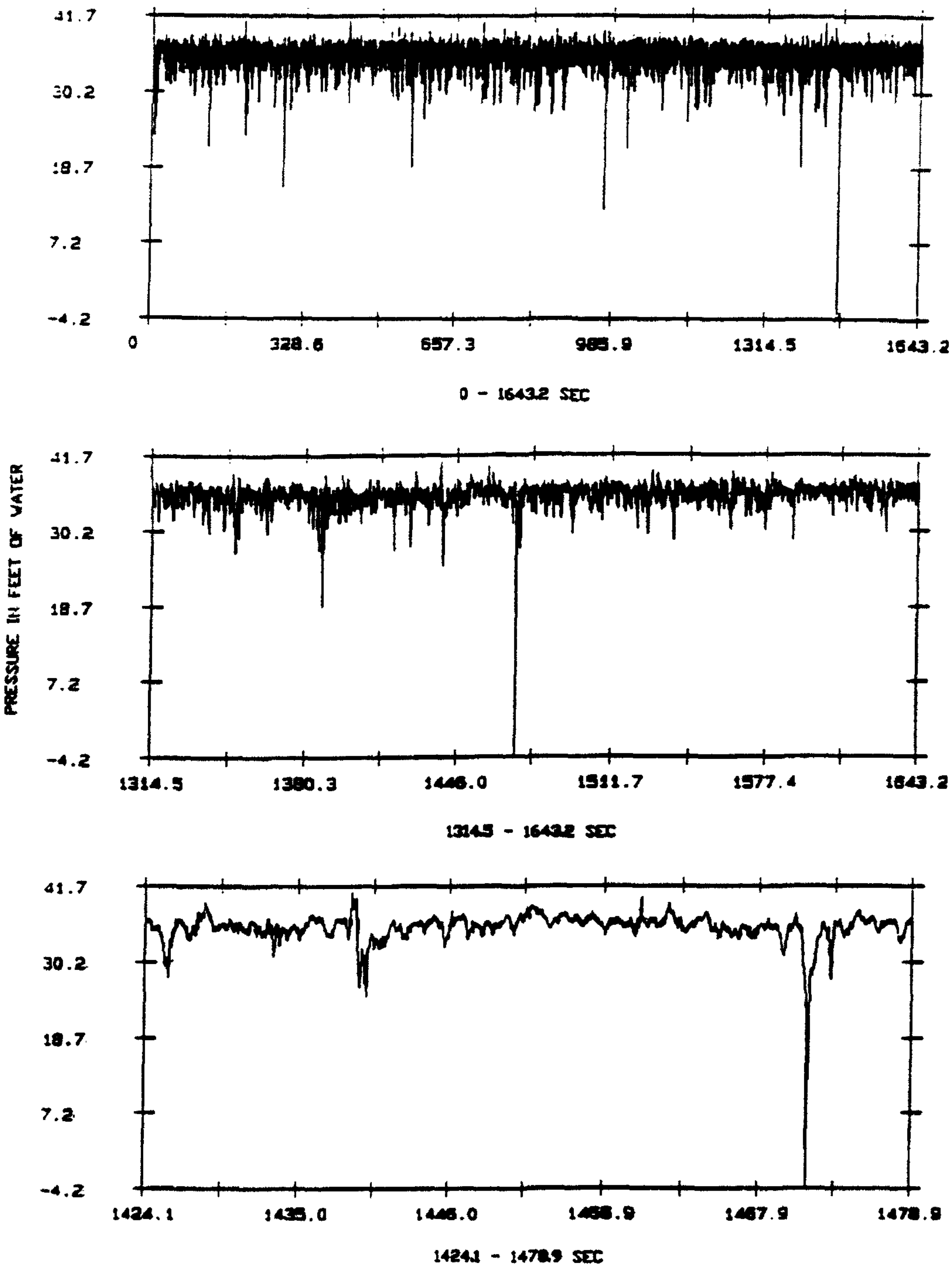


TIME-HISTORY PLOTS
TEST 1
SAMPLING RATE 9.13 SAMPLES/SEC
TRANSDUCER 20

PLATE 5
(Sheet 1 of 2)

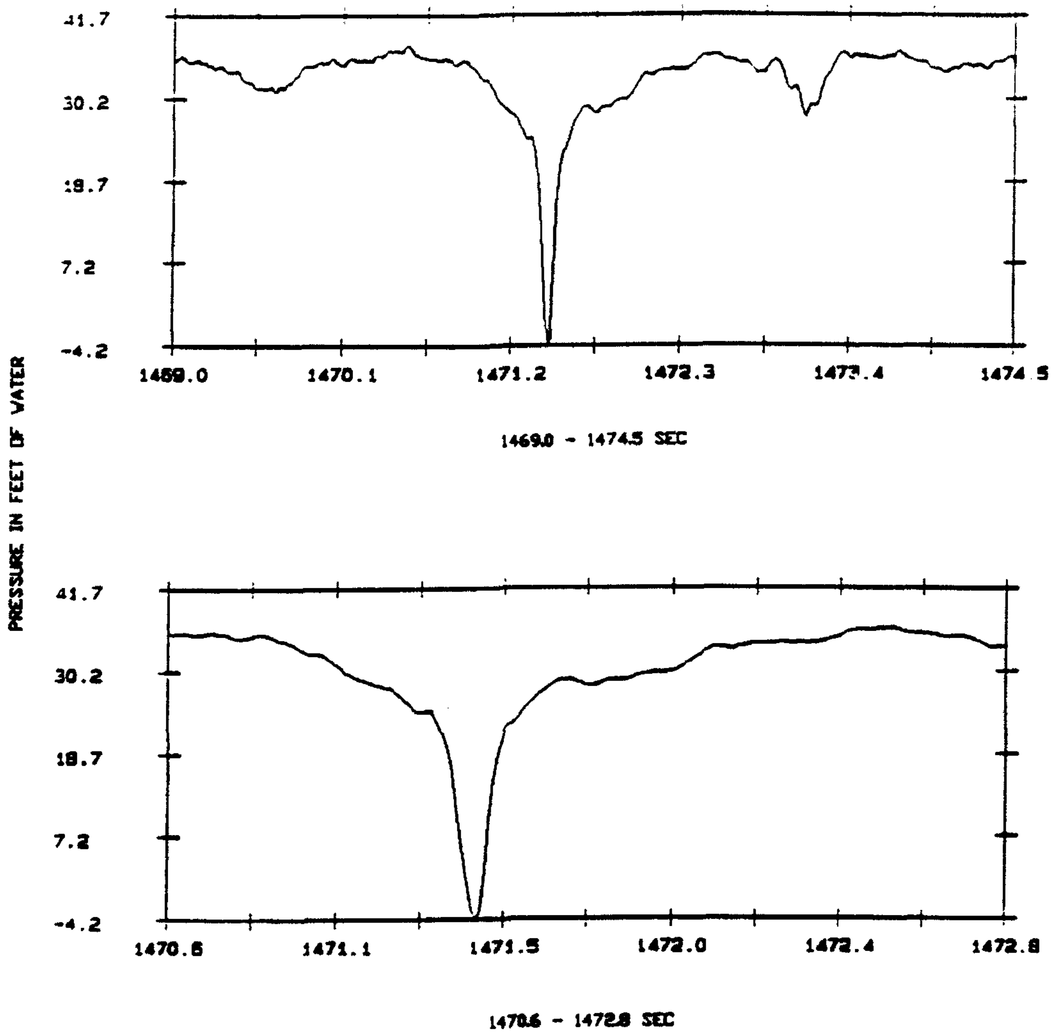


TIME-HISTORY PLOTS
TEST 1
SAMPLING RATE 9.13 SAMPLES/SEC
TRANSDUCER 20

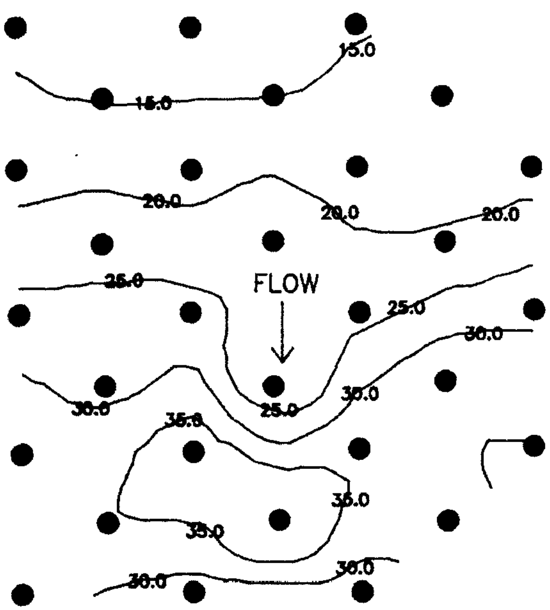


TIME-HISTORY PLOTS
TEST 9
SAMPLING RATE 91.3 SAMPLES/SEC
TRANSDUCER 21

PLATE 6
(Sheet 1 of 2)

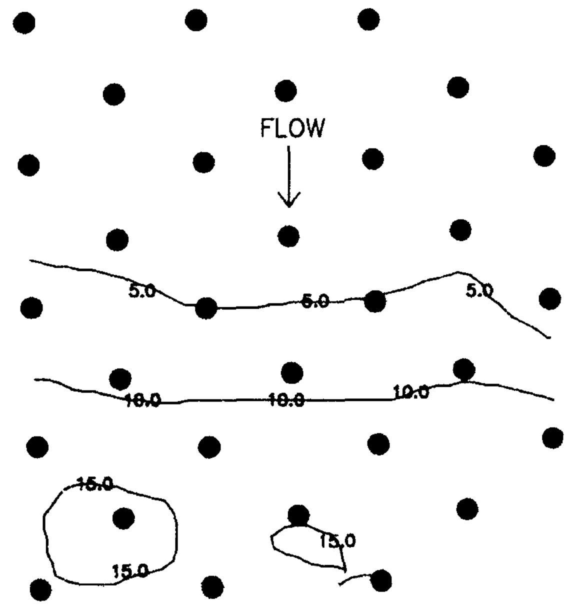


TIME-HISTORY PLOTS
TEST 9
SAMPLING RATE 91.3 SAMPLES/SEC
TRANSDUCER 21



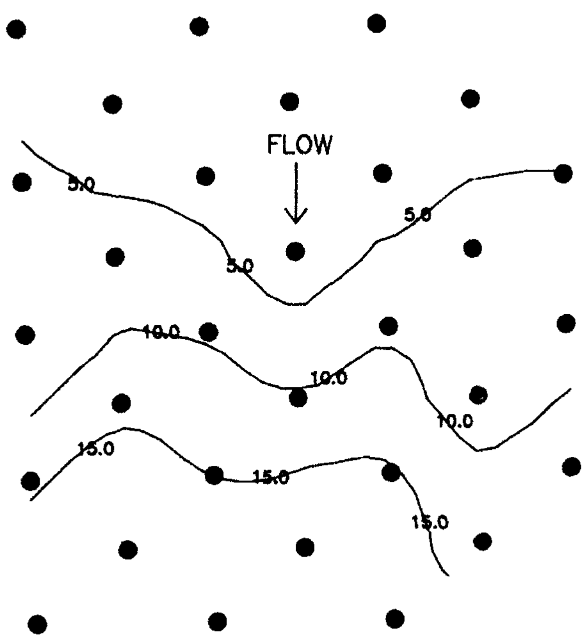
TEST NO.1
TIME: 11998.53
DISCHARGE 65,000 CFS
UPPER POOL 1267.45 FT
LOWER POOL 1258.5 FT
GATE OPENING: FULL

NOTE: PRESSURE CONTOURS ARE IN FEET OF WATER AT 5.0-FT INTERVALS

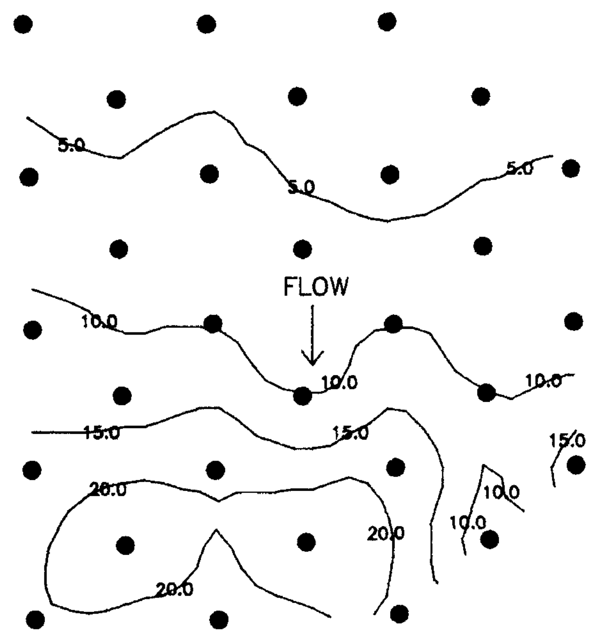


TEST NO.2
TIME: 13011.16
DISCHARGE 10,400 CFS
UPPER POOL 1267.45 FT
LOWER POOL 1237.5 FT
GATE OPENING: 4 FT

PRESSURE CONTOURS
TYPE 1 TRANSDUCER PATTERN
SAMPLING RATE: 9.13 SAMPLES\SEC\CHANNEL
SAMPLING TIME: 19718.03 SEC



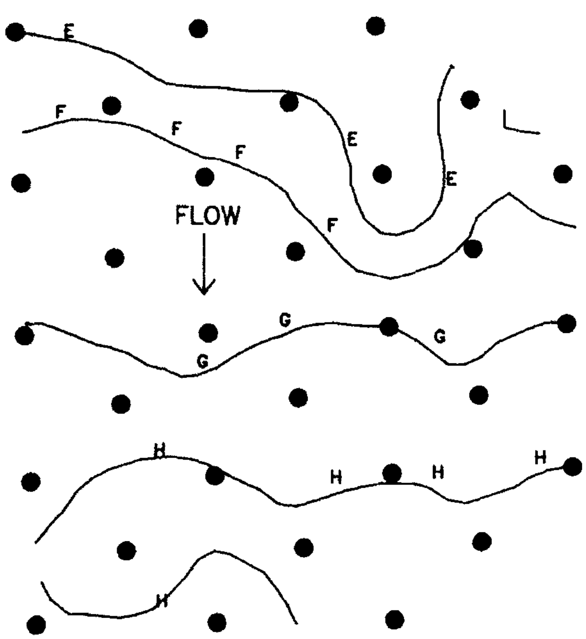
TEST NO.3
TIME: 19462.46
DISCHARGE 19,600 CFS
UPPER POOL 1271.8 FT
LOWER POOL 1242.0 FT
GATE OPENING: 7 FT



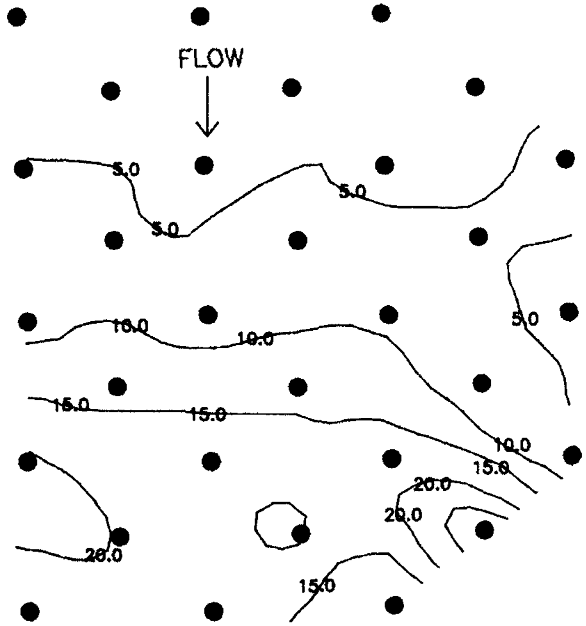
TEST NO.4
TIME: 9598.95
DISCHARGE 24,600 CFS
UPPER POOL 1271.08 FT
LOWER POOL 1243.5 FT
GATE OPENING: 9 FT

NOTE: PRESSURE CONTOURS ARE IN FEET OF WATER AT 5.0-FT INTERVALS

PRESSURE CONTOURS
TYPE 1 TRANSDUCER PATTERN
SAMPLING RATE: 9.13 SAMPLES\SEC\CHANNEL
SAMPLING TIME: 19718.03 SEC



TEST NO.5
TIME: 7430.95
DISCHARGE 28,000 CFS
UPPER POOL 1276.0 FT
LOWER POOL 1254.0 FT
GATE OPENING 9 FT

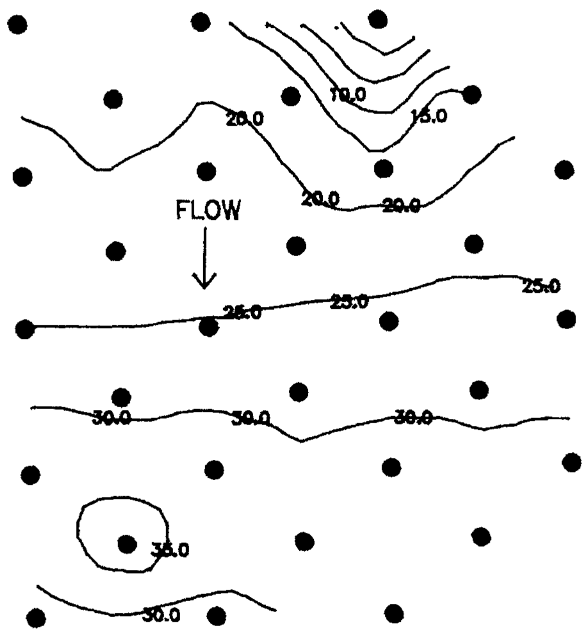


TEST NO.6
TIME: 2004.33
DISCHARGE 33,000 CFS
UPPER POOL 1271.13 FT
LOWER POOL 1245.0 FT
GATE OPENING 12 FT

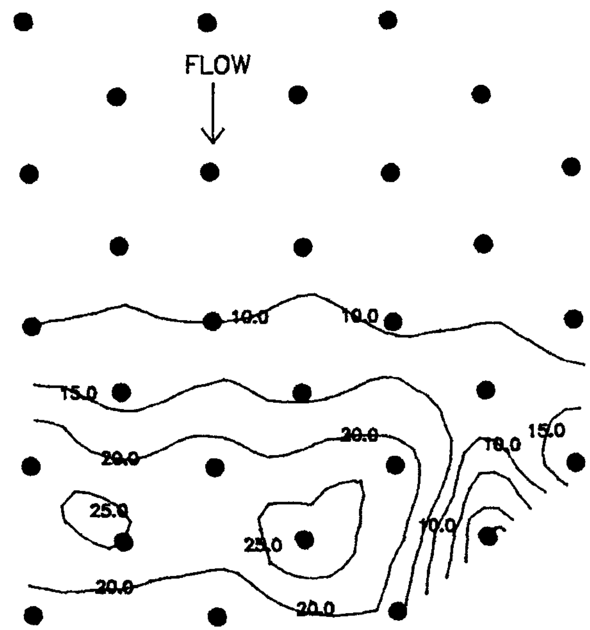
NOTE: PRESSURE CONTOURS ARE IN FEET OF WATER AT 5.0-FT INTERVALS

PRESSURE CONTOURS
TYPE 1 TRANSDUCER PATTERN
SAMPLING RATE: 9.13 SAMPLES\SEC\CHANNEL
SAMPLING TIME: 19718.03 SEC

PLATE 7
(Sheet 3 of 4)



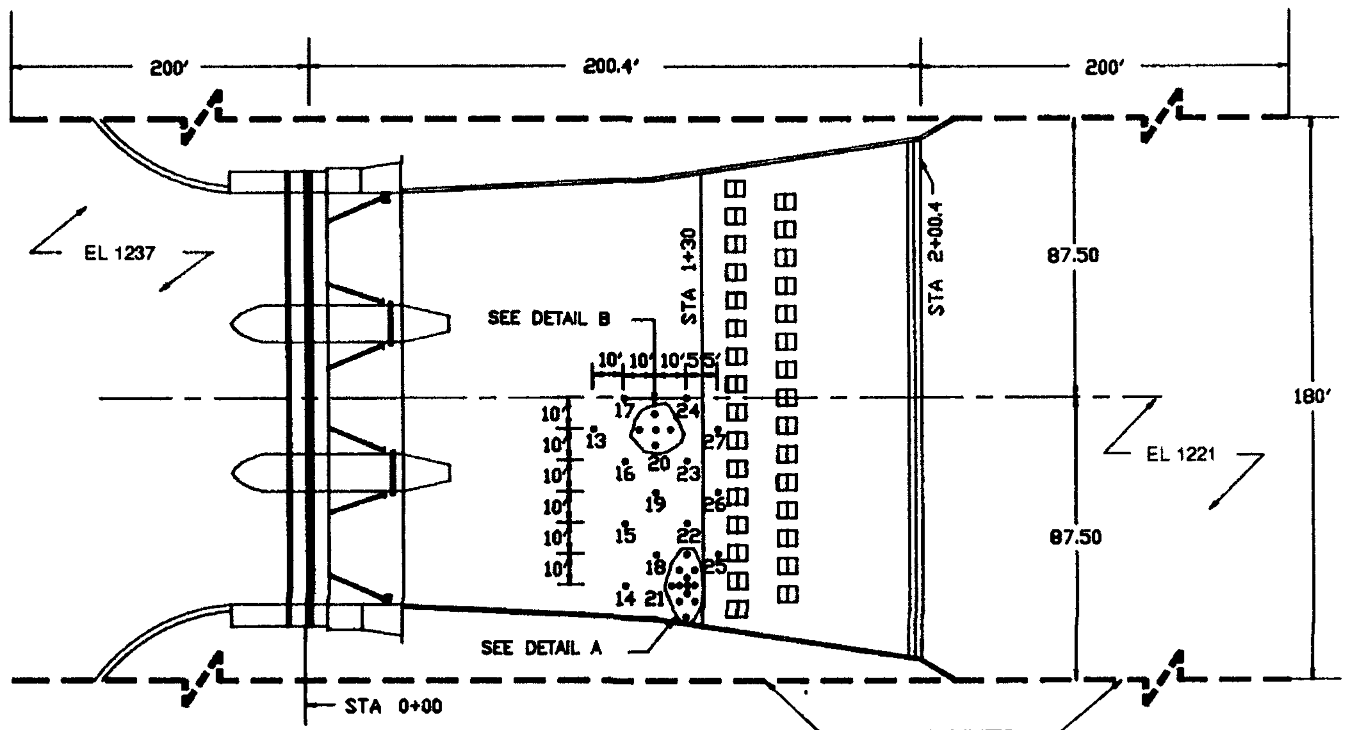
TEST NO.7
TIME: 12023.72
DISCHARGE 52,500 CFS
UPPER POOL 1277.0 FT
LOWER POOL 1255.5 FT
GATE OPENING: 12 FT



TEST NO.8
TIME: 10066.36
DISCHARGE 43,100 CFS
UPPER POOL 1265.6 FT
LOWER POOL 1247.2 FT
GATE OPENING: FULL

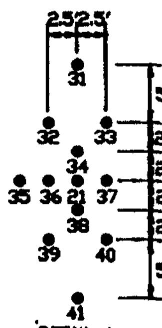
NOTE: PRESSURE CONTOURS ARE IN FEET OF WATER AT 5.0-FT INTERVALS

PRESSURE CONTOURS
TYPE 1 TRANSDUCER PATTERN
SAMPLING RATE: 9.13 SAMPLES\SEC\CHANNEL
SAMPLING TIME: 19718.03 SEC

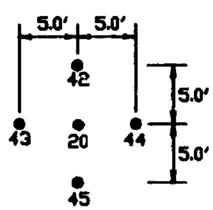


TRANSDUCER ELEVATIONS

NO.	ELEVATION	NO.	ELEVATION
13	122.730	31	1222.76
14	1225.79	32	1223.14
15	1225.79	33	1222.38
16	1225.79	34	1222.76
17	1225.79	35	1223.52
18	1224.27	36	1223.14
19	1224.27	37	1222.38
20	1224.27	38	1222.76
21	1224.27	39	1223.14
22	1222.76	40	1222.38
23	1222.76	41	1222.76
24	1222.76	42	1224.27
25	1222.76	43	1225.03
26	1222.00	44	1223.51
27	1222.00	45	1224.27

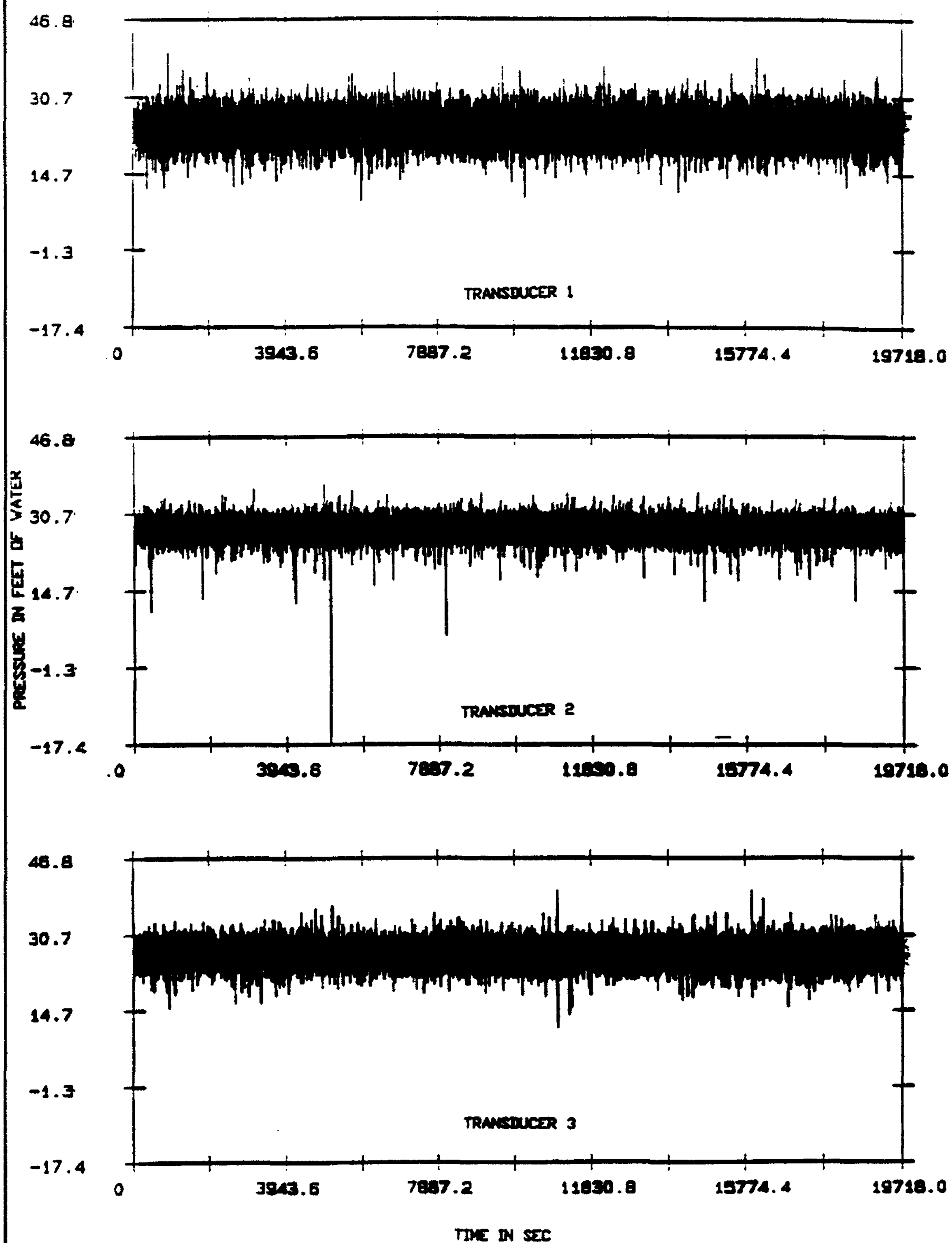


DETAIL A



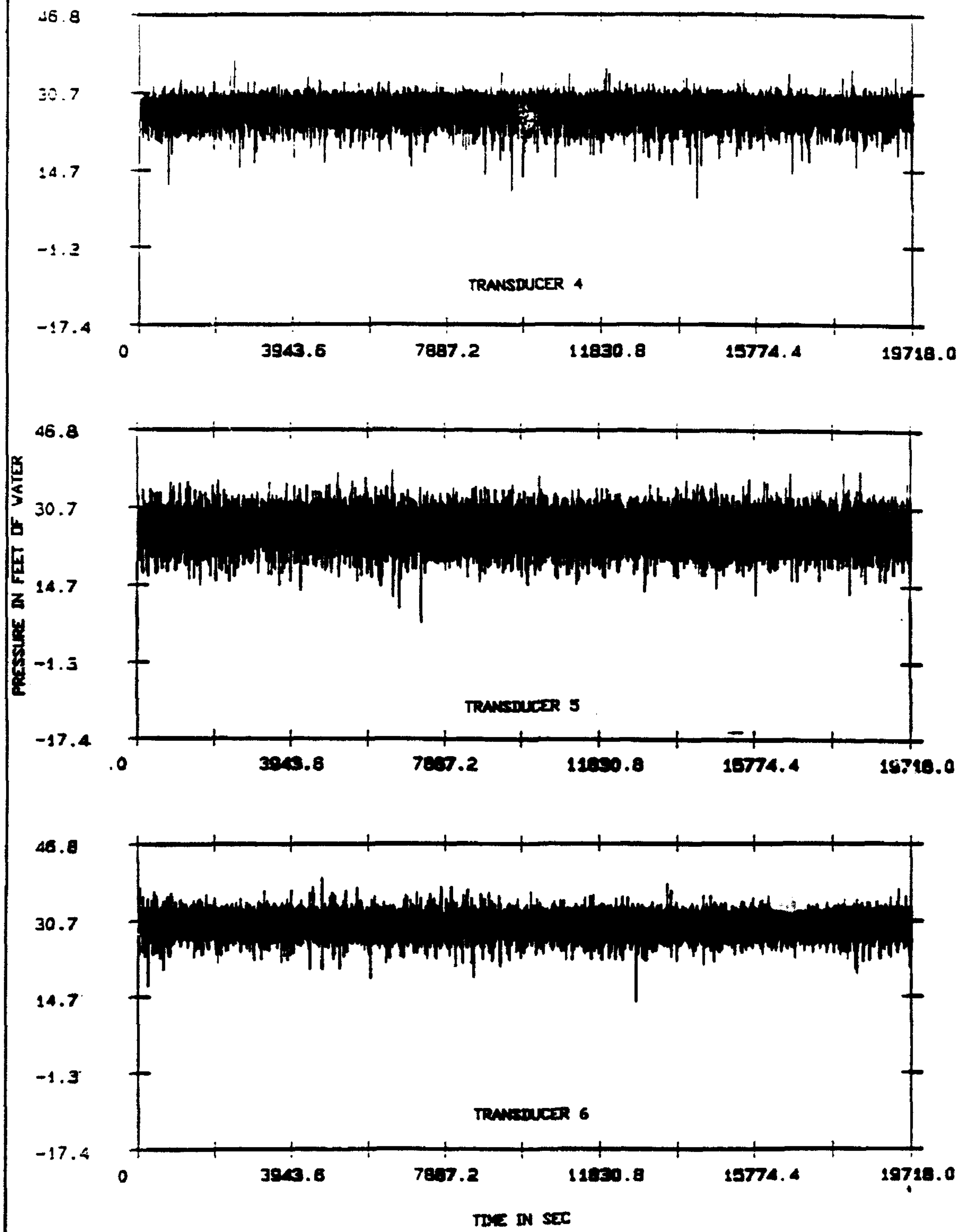
DETAIL B

TRANSDUCER LOCATIONS
TYPE 2 PATTERN



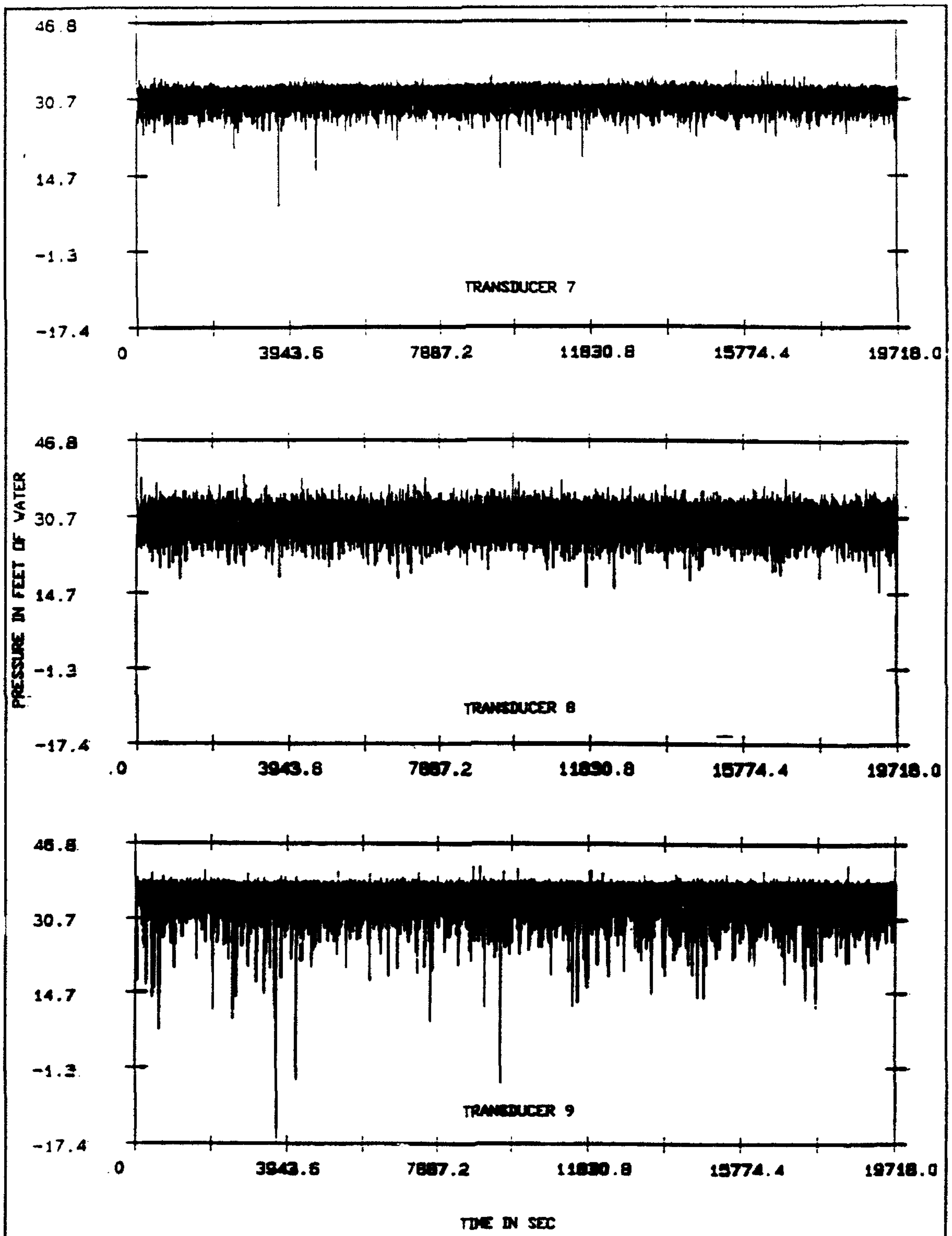
TIME-HISTORY PLOTS
TEST 11

PLATE 9
(Sheet 1 of 10)



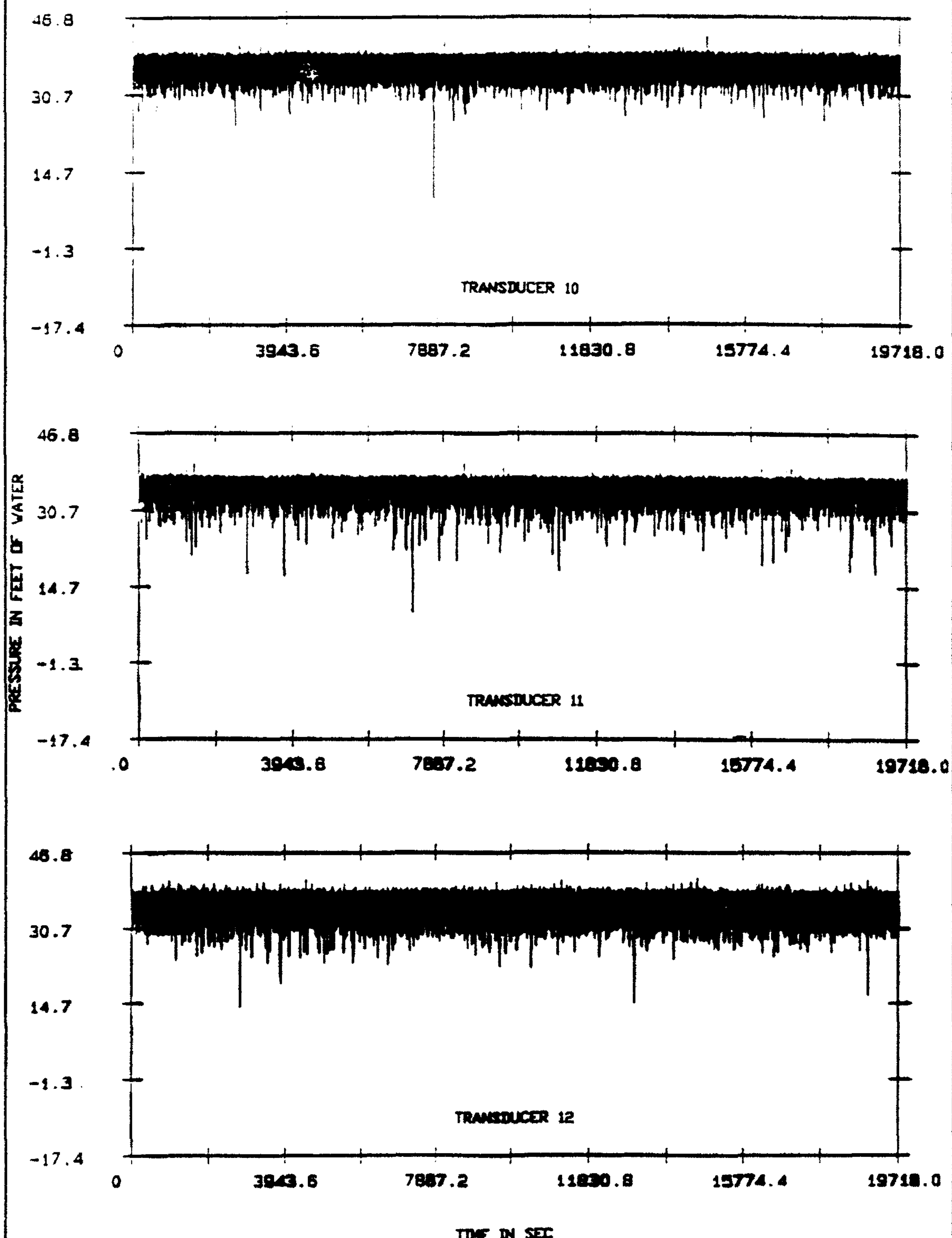
TIME-HISTORY PLOTS
TEST 11

PLATE 9
(Sheet 2 of 10)



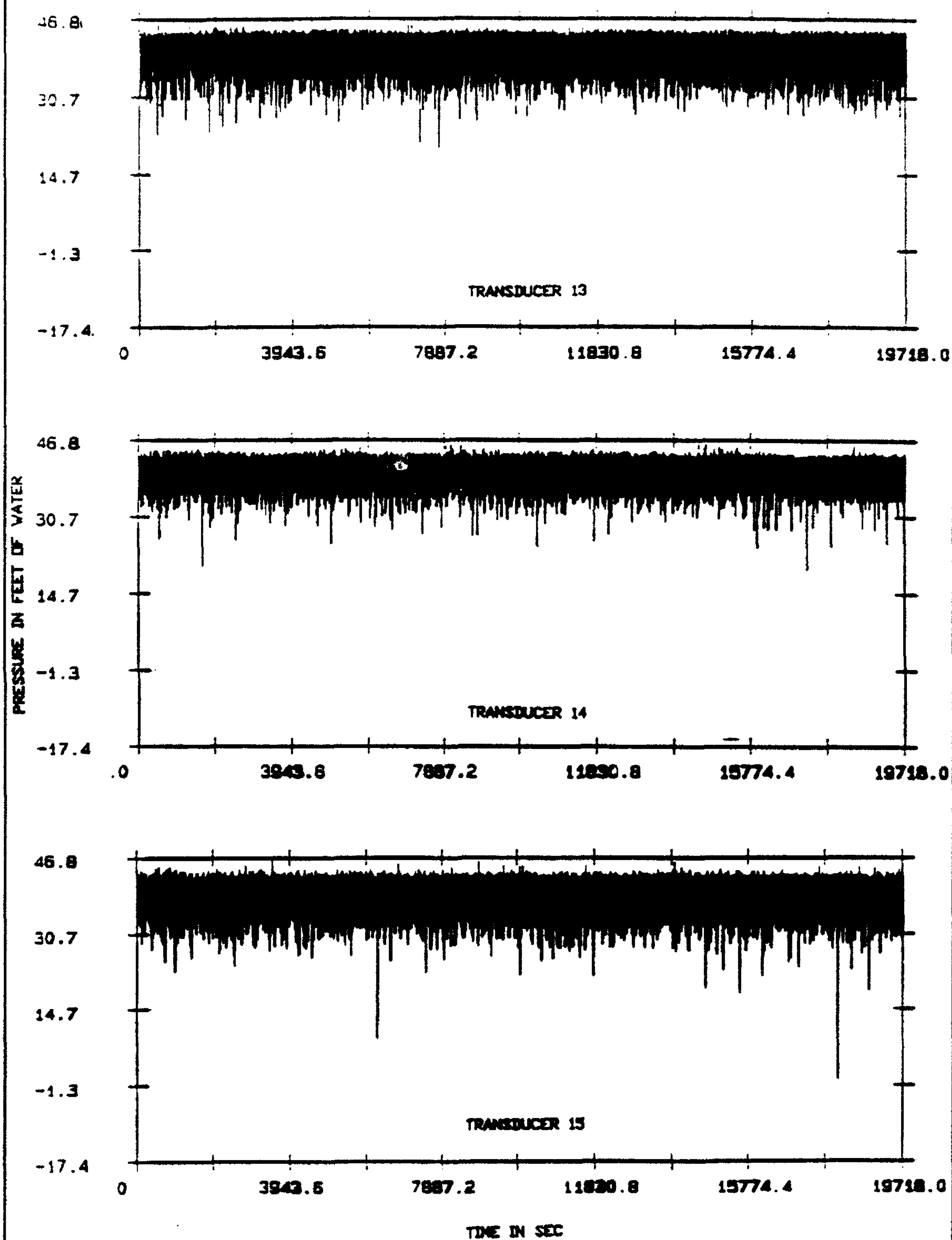
TIME-HISTORY PLOTS
TEST 11

PLATE 9
(Sheet 3 of 10)



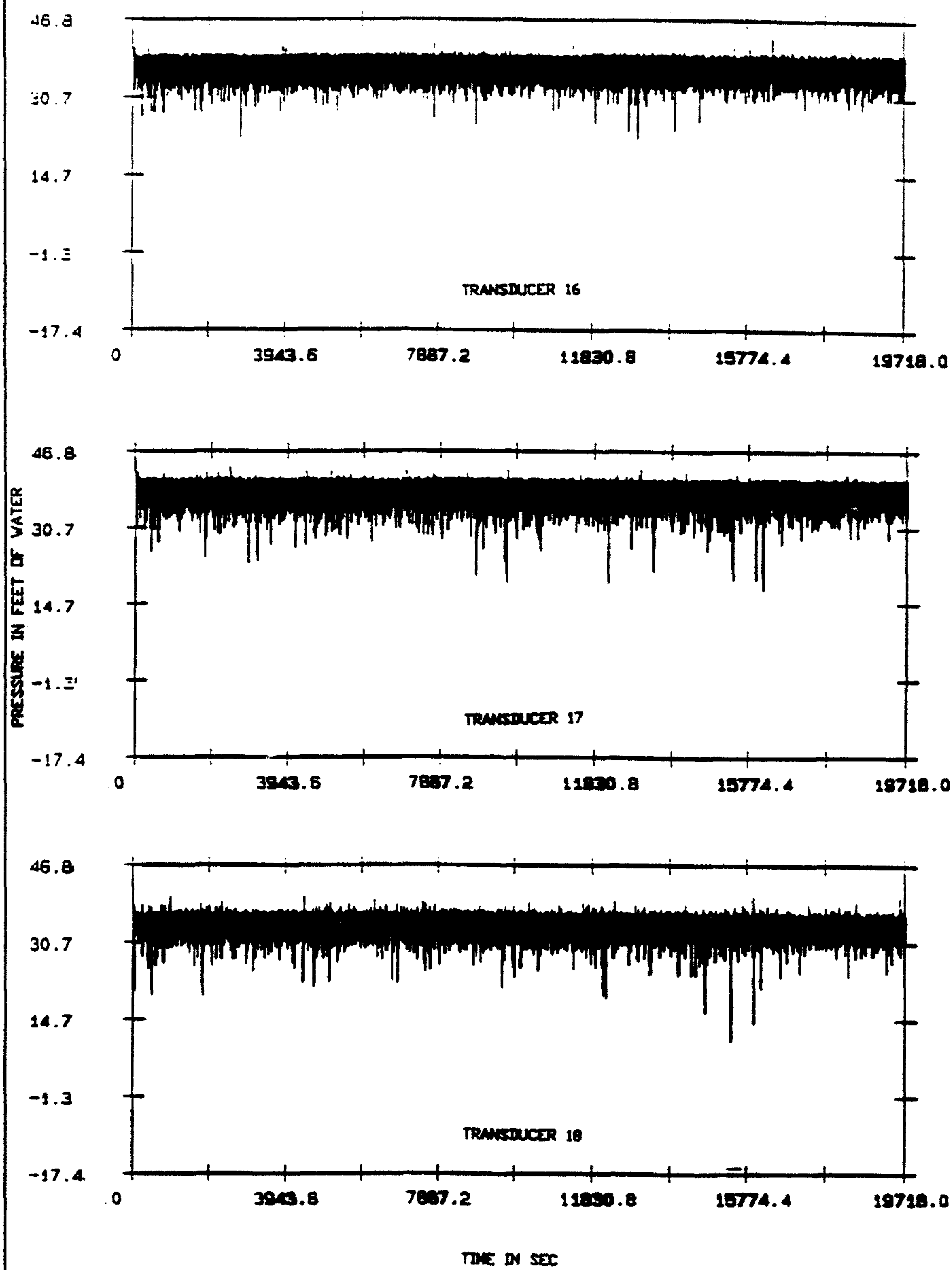
TIME-HISTORY PLOTS
TEST 11

PLATE 9
(Sheet 4 of 10)



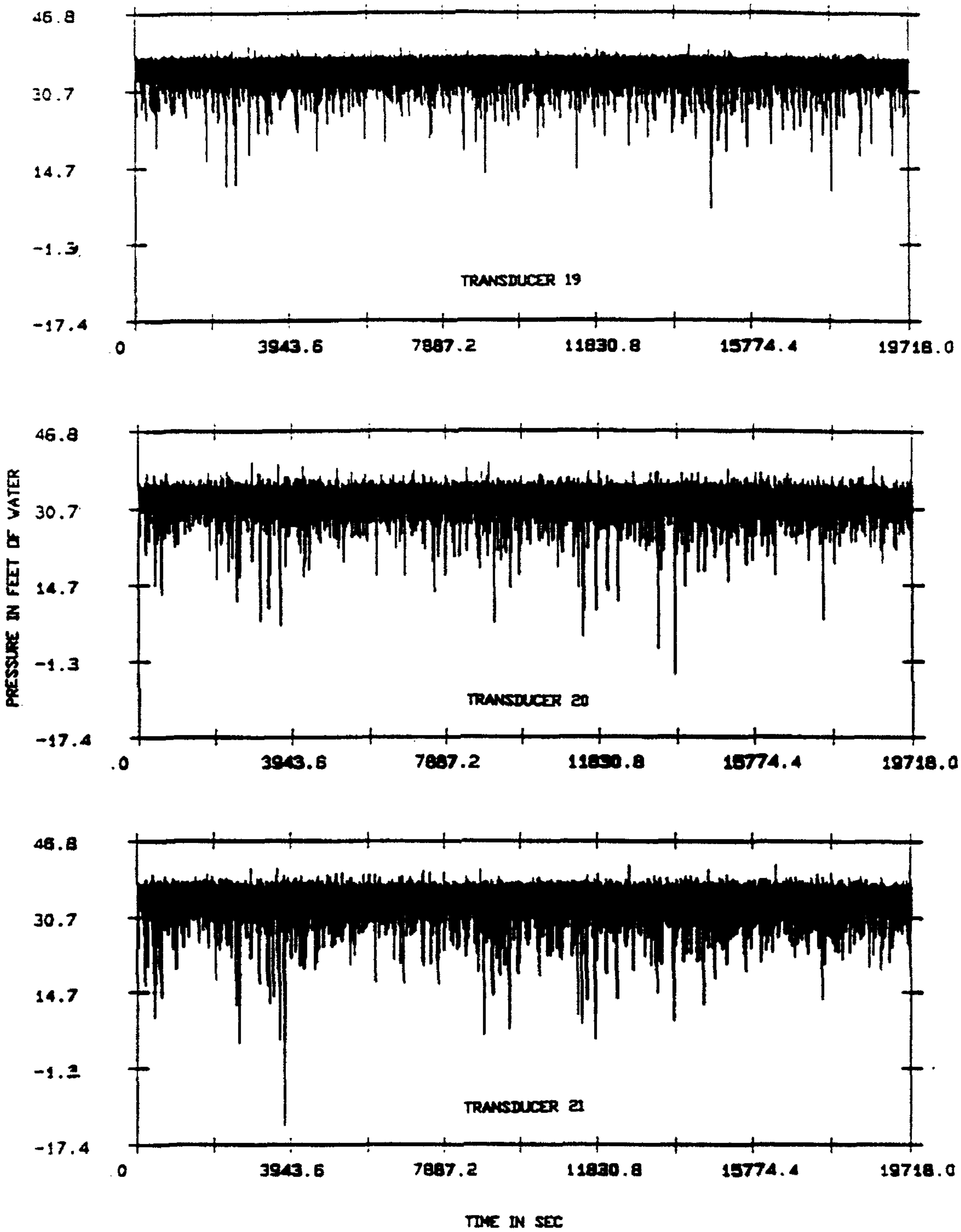
TIME-HISTORY PLOTS
TEST 11

PLATE 9
(Sheet 5 of 10)

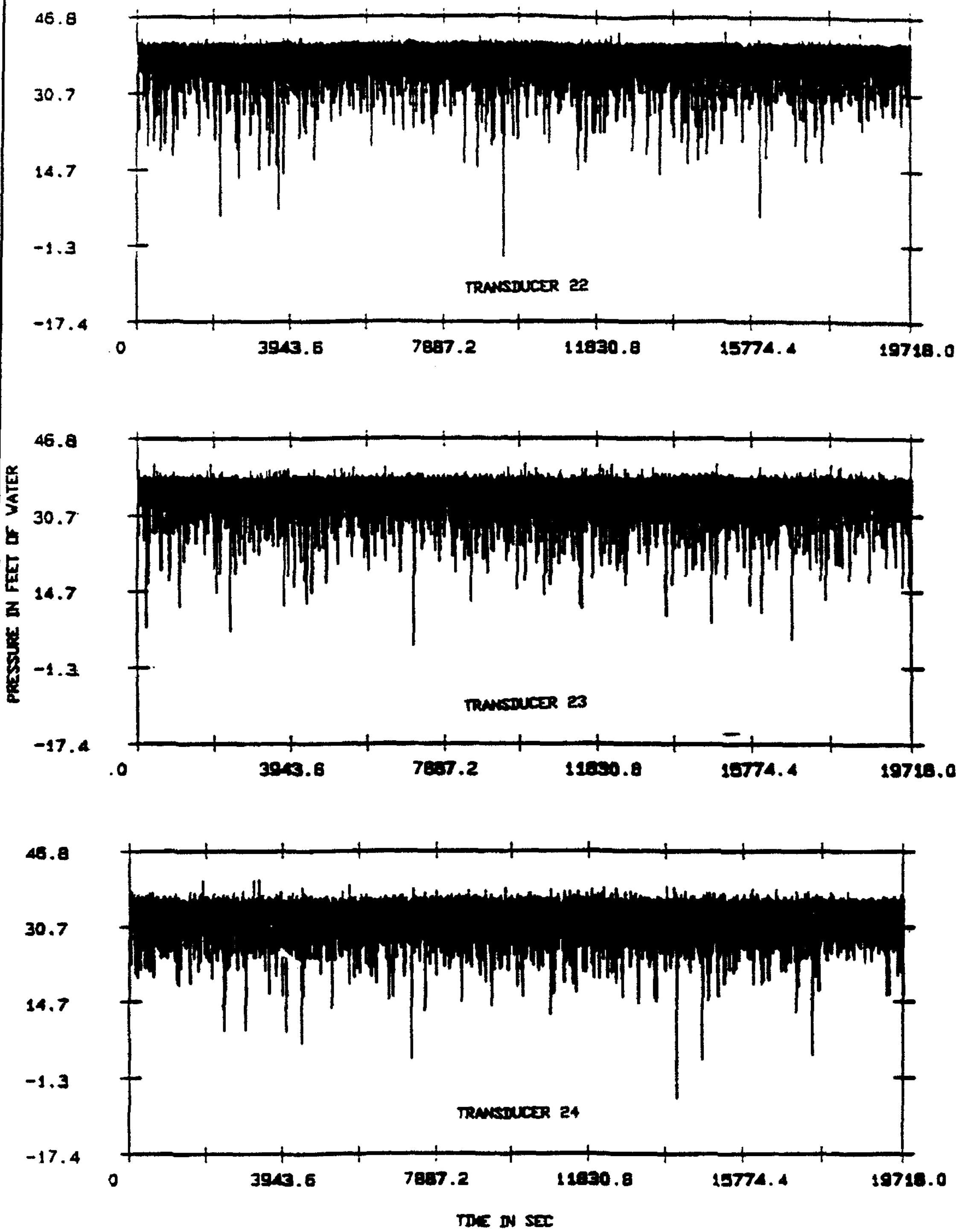


TIME-HISTORY PLOTS
TEST 11

PLATE 9
(Sheet 6 of 10)

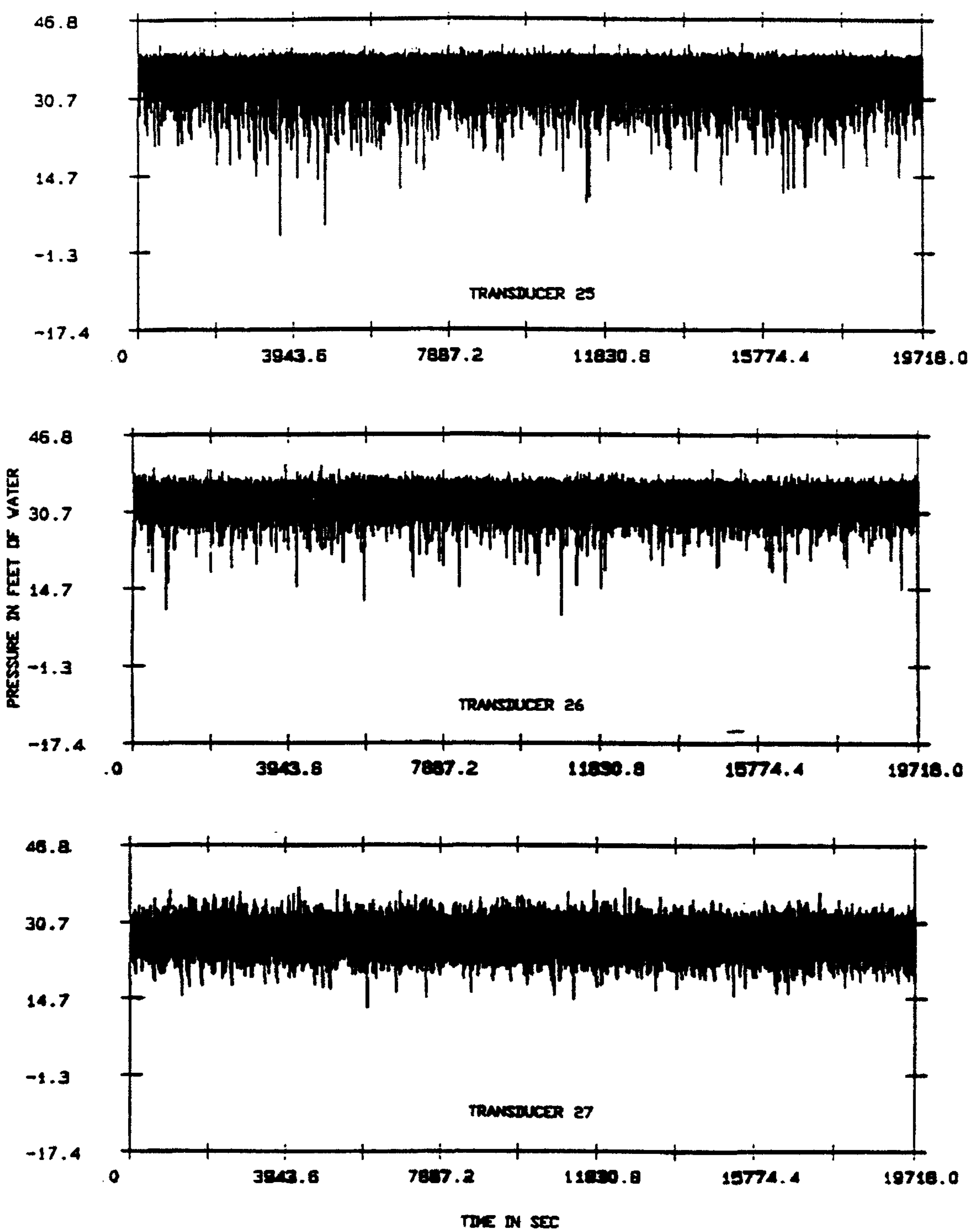


TIME HISTORY PLOTS
TEST 11



TIME-HISTORY PLOTS
TEST 11

PLATE 9
(Sheet 8 of 10)



TIME-HISTORY PLOTS
TEST 11

PLATE 9
(Sheet 9 of 10)

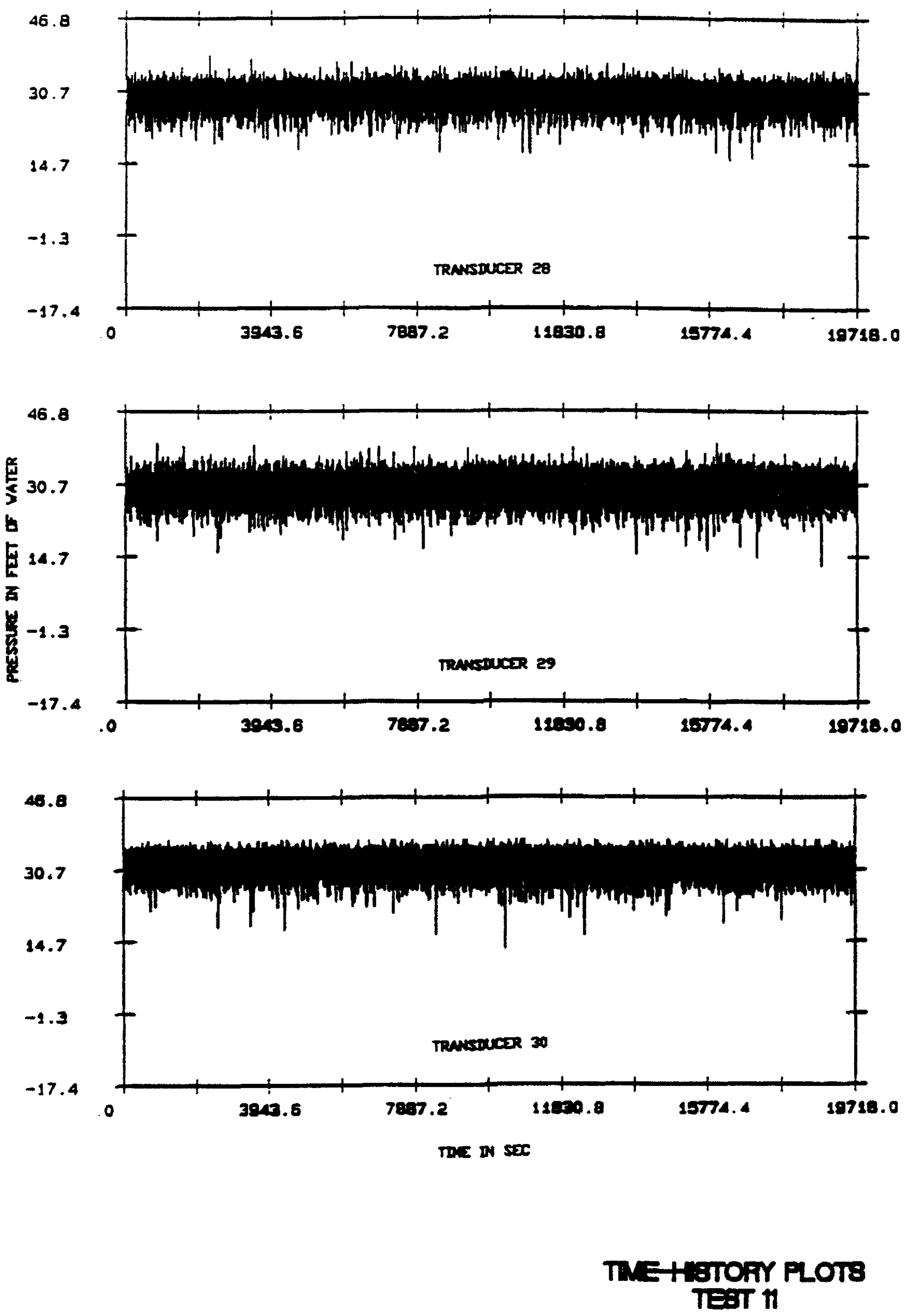
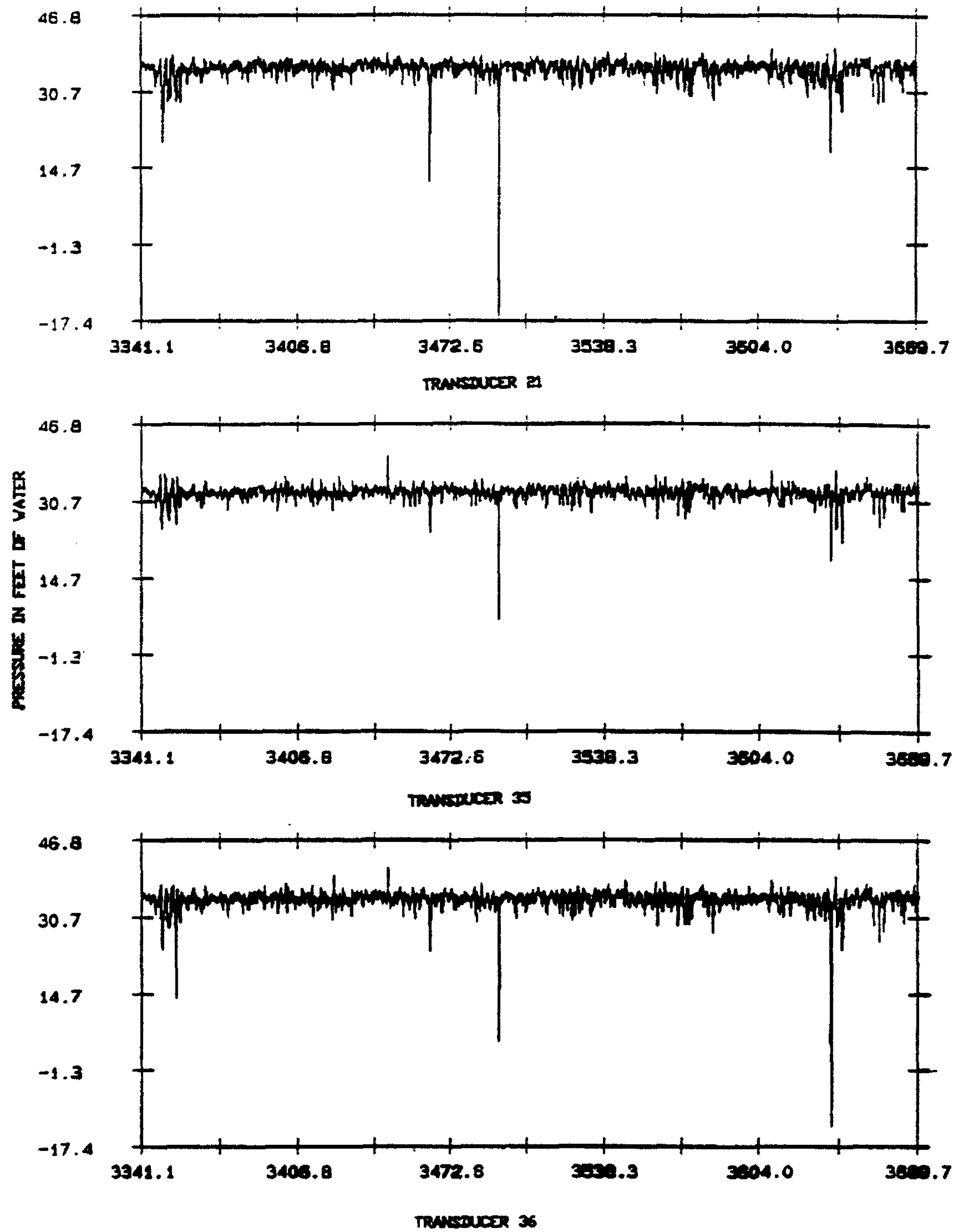
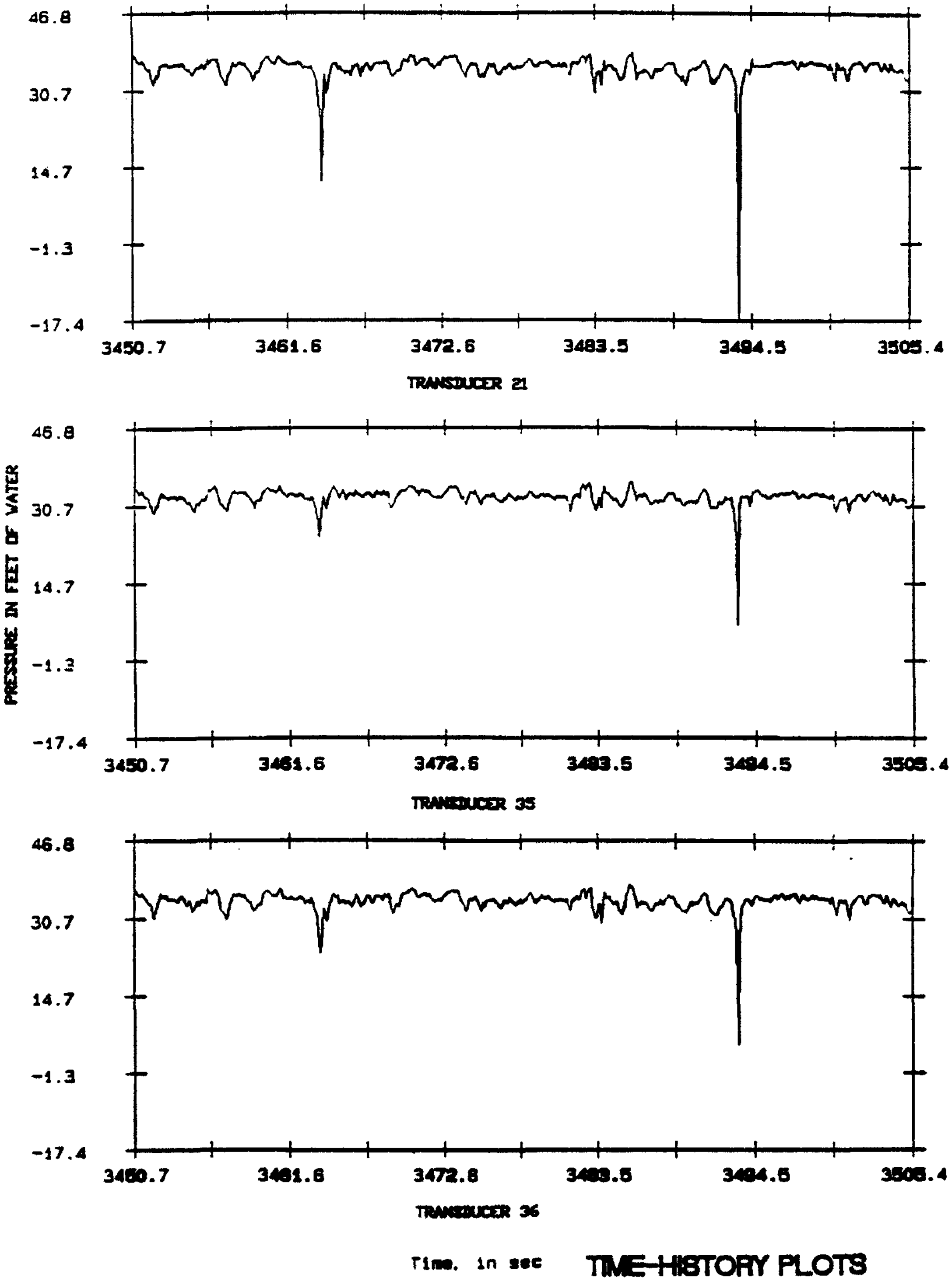


PLATE 9
(Sheet 10 of 10)

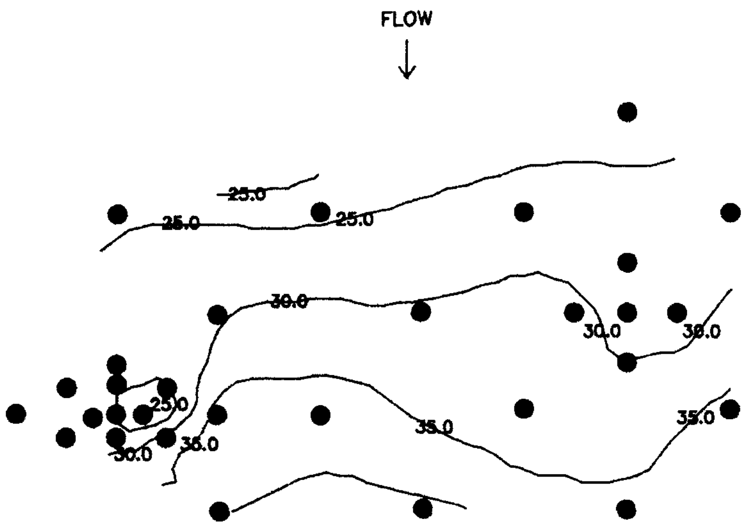


TIME-HISTORY PLOTS
TEST 11
SAMPLING RATE 91.3 SAMPLES/SEC
TRANSDUCERS 21,35,36

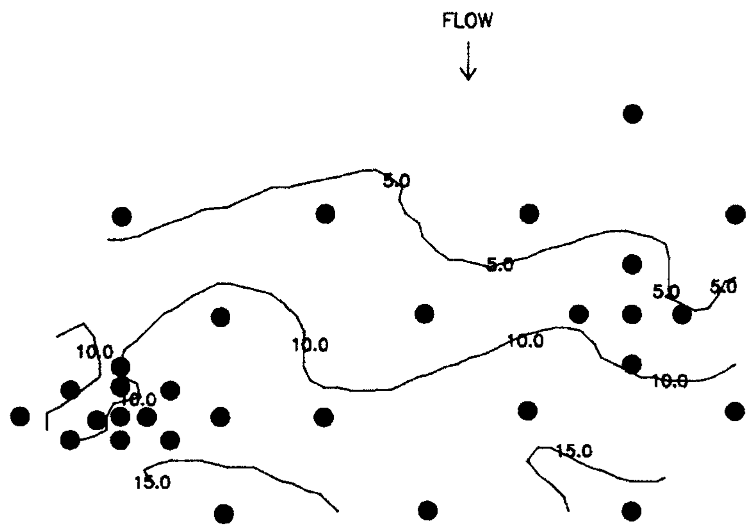


TIME-HISTORY PLOTS
TEST 11
SAMPLING RATE 913 SAMPLES/SEC
TRANSDUCERS 21,35,36

PLATE 10
(Sheet 2 of 2)



TEST NO.11
TIME: 13786.3
DISCHARGE 65,000 CFS
UPPER POOL 1277.11 FT
LOWER POOL 1258.5 FT
GATE OPENING: FULL

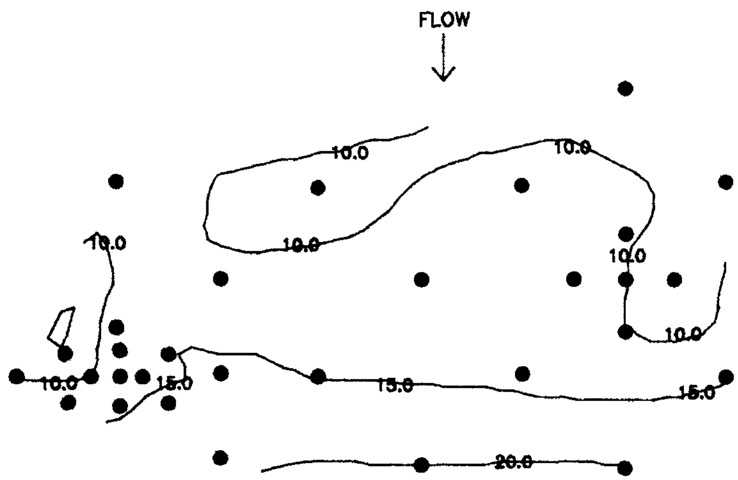


TEST NO.12
TIME: 4053.91
DISCHARGE 10,400 CFS
UPPER POOL 1267.45 FT
LOWER POOL 1237.5 FT
GATE OPENING: 4 FT

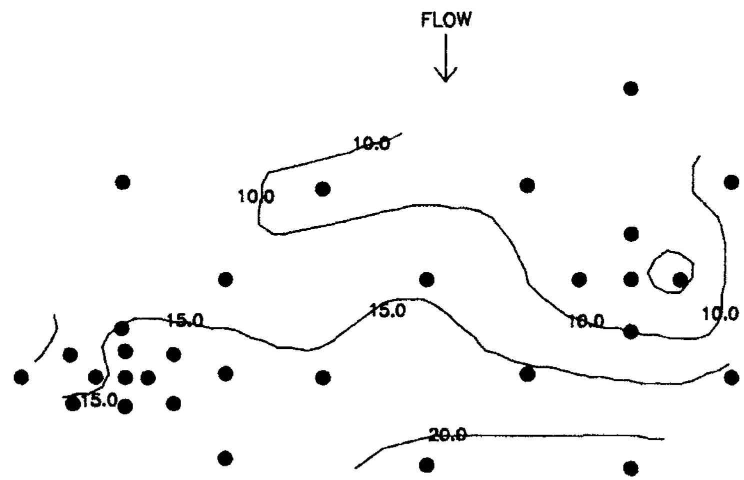
NOTE: PRESSURE CONTOURS ARE IN FEET OF WATER AT 5.0-FT INTERVALS

PRESSURE CONTOURS

TYPE 2 TRANSDUCER PATTERN
SAMPLING RATE: 9.31 SAMPLES\SEC\CHANNEL
SAMPLING TIME: 19,718.03 SEC



TEST NO.13
TIME: 18008.41
DISCHARGE 19,600 CFS
UPPER POOL 1271.18 FT
LOWER POOL 1242.0 FT
GATE OPENING 7 FT

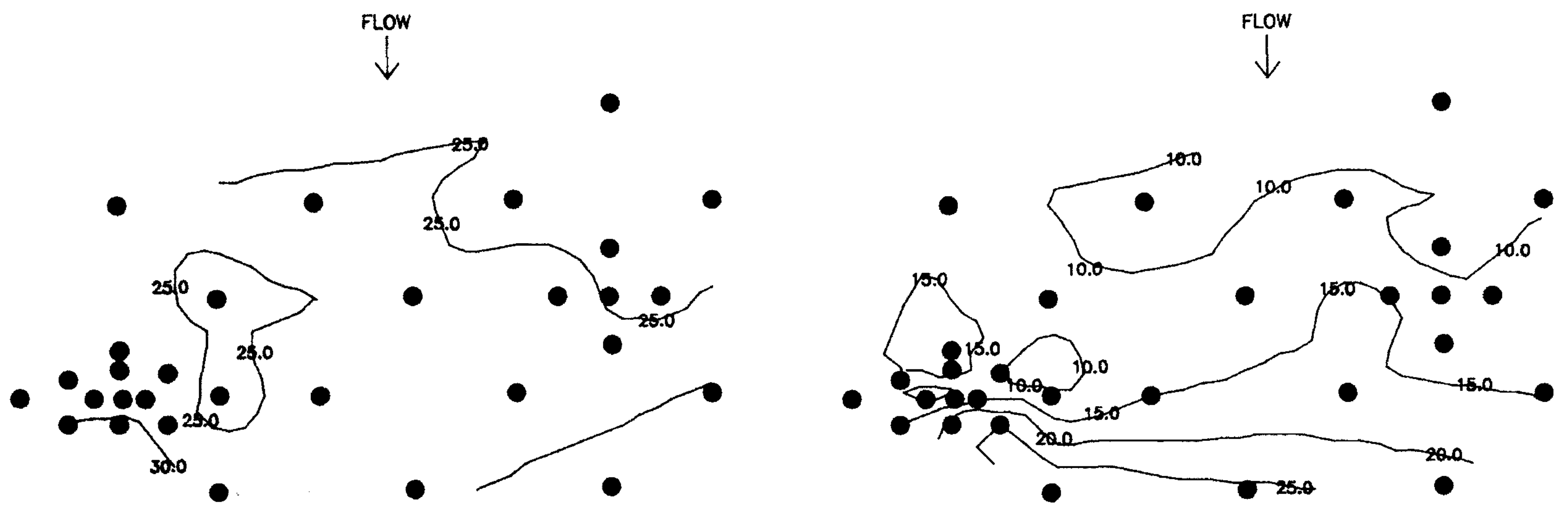


TEST NO.14
TIME: 18041.67
DISCHARGE 24,600 CFS
UPPER POOL 1271.08 FT
LOWER POOL 1243.5 FT
GATE OPENING 9 FT

NOTE: PRESSURE CONTOURS ARE IN FEET OF WATER AT 5.0-FT INTERVALS

PRESSURE CONTOURS
TYPE 2 TRANSDUCER PATTERN
SAMPLING RATE: 9.31 SAMPLES\SEC\CHANNEL
SAMPLING TIME: 19,718.03 SEC

PLATE 11
(Sheet 2 of 4)



TEST NO.15
TIME: 10707.00
DISCHARGE 28,000 CFS
UPPER POOL 1276.0 FT
LOWER POOL 1254.0 FT
GATE OPENING: 9 FT

TEST NO.16
TIME: 4048.76
DISCHARGE 33,000 CFS
UPPER POOL 1271.13 FT
LOWER POOL 1245.0 FT
GATE OPENING: 12 FT

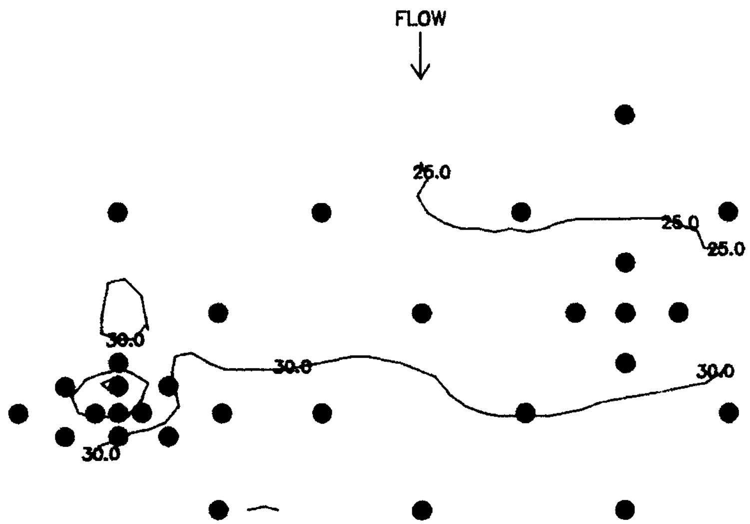
NOTE: PRESSURE CONTOURS ARE IN FEET OF WATER AT 5.0-FT INTERVALS

PRESSURE CONTOURS

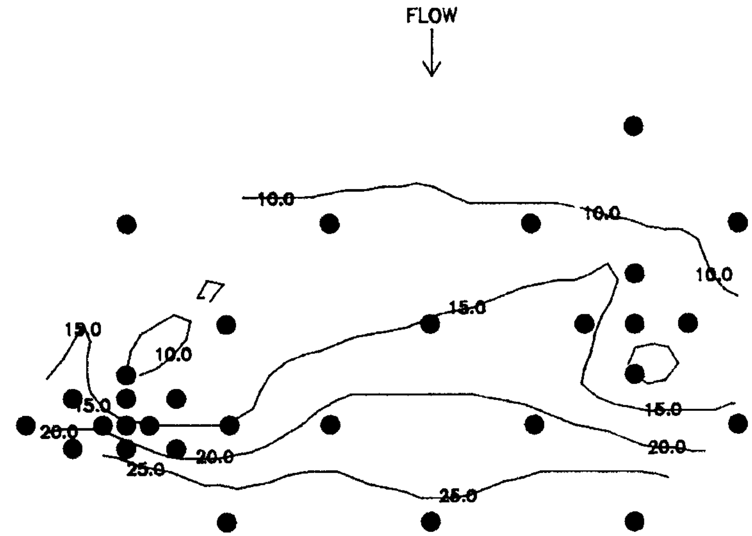
TYPE 2 TRANSDUCER PATTERN

SAMPLING RATE: 9.31 SAMPLES\SEC\CHANNEL

SAMPLING TIME: 19,718.03 SEC



TEST NO.17
TIME: 13622.45
DISCHARGE 52,500 CFS
UPPER POOL 1277.0 FT
LOWER POOL 1255.5 FT
GATE OPENING: 12 FT

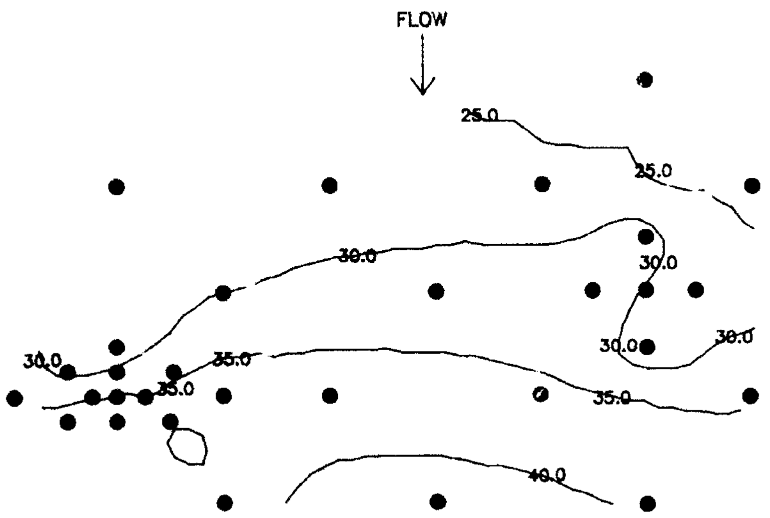


TEST NO.18
TIME: 15603.53
DISCHARGE 43,100 CFS
UPPER POOL FT
LOWER POOL 1247.2 FT
GATE OPENING: FULL

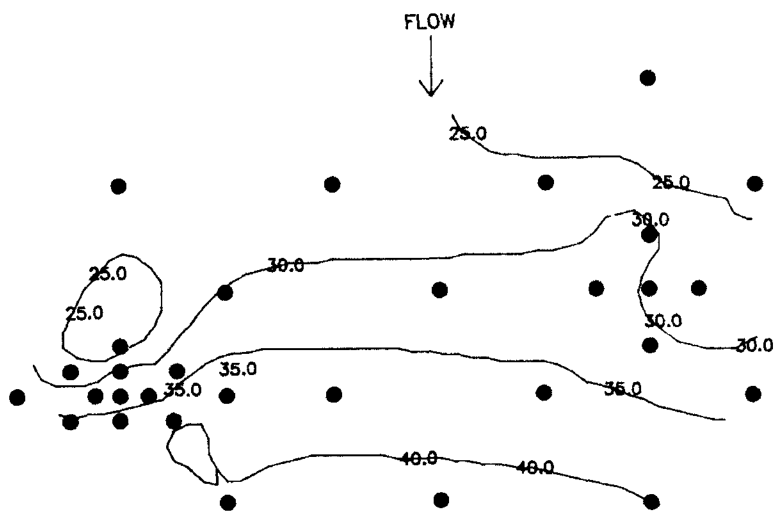
NOTE: PRESSURE CONTOURS ARE IN FEET OF WATER AT 5.0-FT INTERVALS

PRESSURE CONTOURS
TYPE 2 TRANSDUCER PATTERN
SAMPLING RATE: 9.31 SAMPLES\SEC\CHANNEL
SAMPLING TIME: 19,718.03 SEC

PLATE 11
(Sheet 4 of 4)



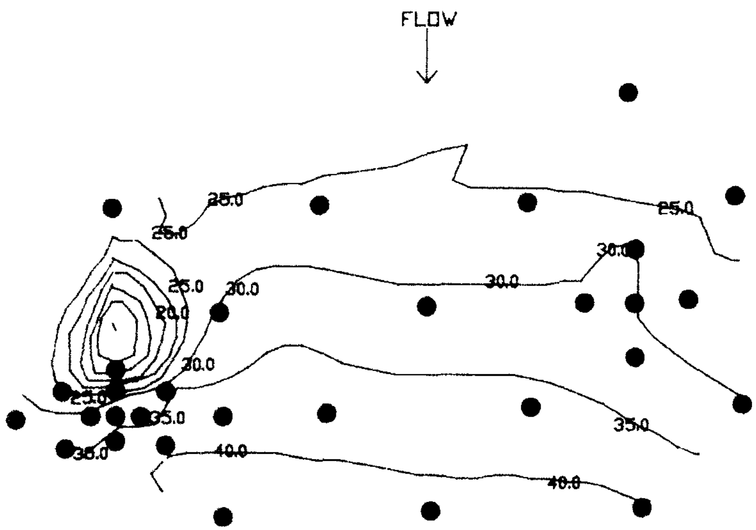
RECORDED 3,493.049 SEC



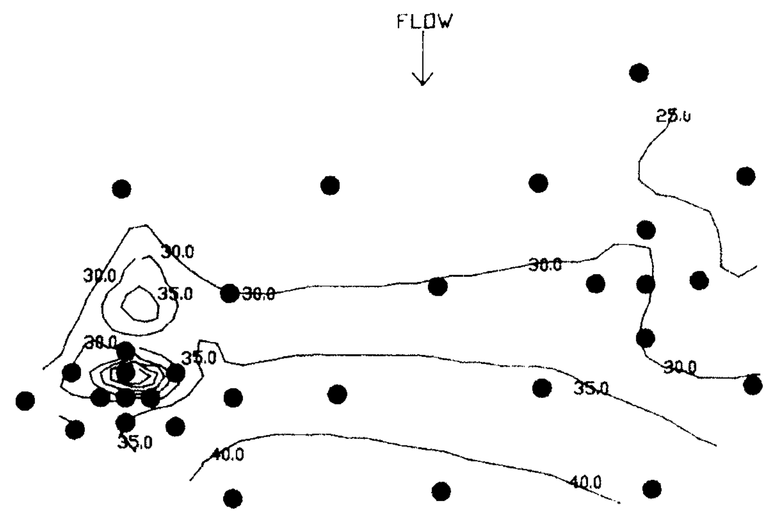
RECORDED 3,493.158 SEC

NOTE: MINIMUM PULSE OF -17.4 FT
OCCURRED AT 3493.569 SEC

PRESSURE CONTOURS IN CHRONOLOGICAL SERIES
3493.049 SEC TO 3494.144 SEC
TYPE 2 TRANSDUCER PATTERN, TEST NO.11
DISCHARGE 65,000 CFS
UPPER POOL 1277.1 FT
LOWER POOL 1258.5 FT
GATE OPENINGS: FULL



RECORDED 3,493.268 SEC

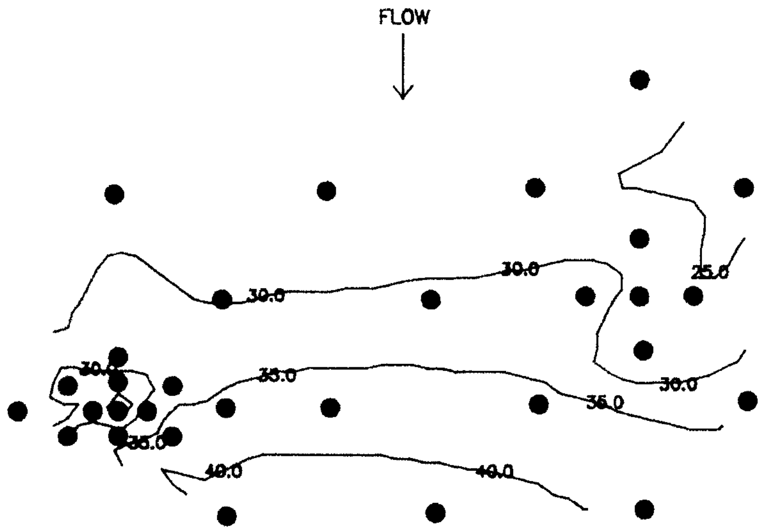


RECORDED 3,493.377 SEC

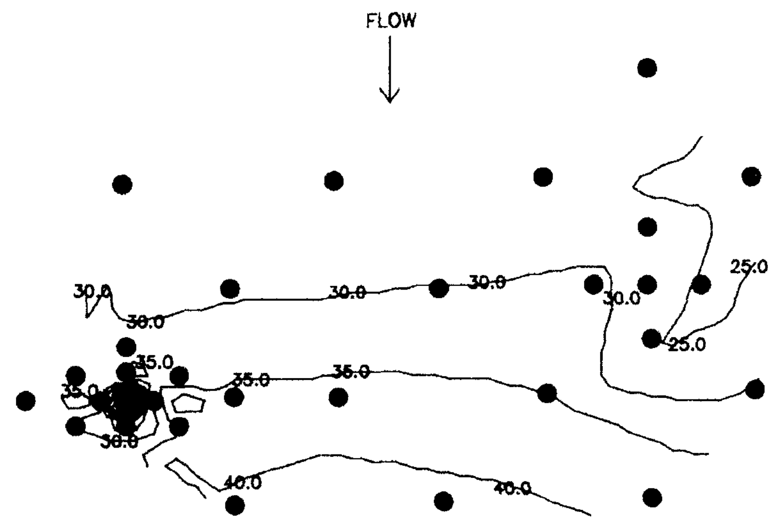
NOTE: MINIMUM PULSE OF -17.4 FT
OCCURRED AT 3493.569 SEC

PRESSURE CONTOURS IN CHRONOLOGICAL SERIES
3493.049 SEC TO 3494.144 SEC
TYPE 2 TRANSDUCER PATTERN, TEST NO.11
DISCHARGE 65,000 CFS
UPPER POOL 1277.1 FT
LOWER POOL 1258.5 FT
GATE OPENINGS: FULL

PLATE 12
(Sheet 2 of 6)



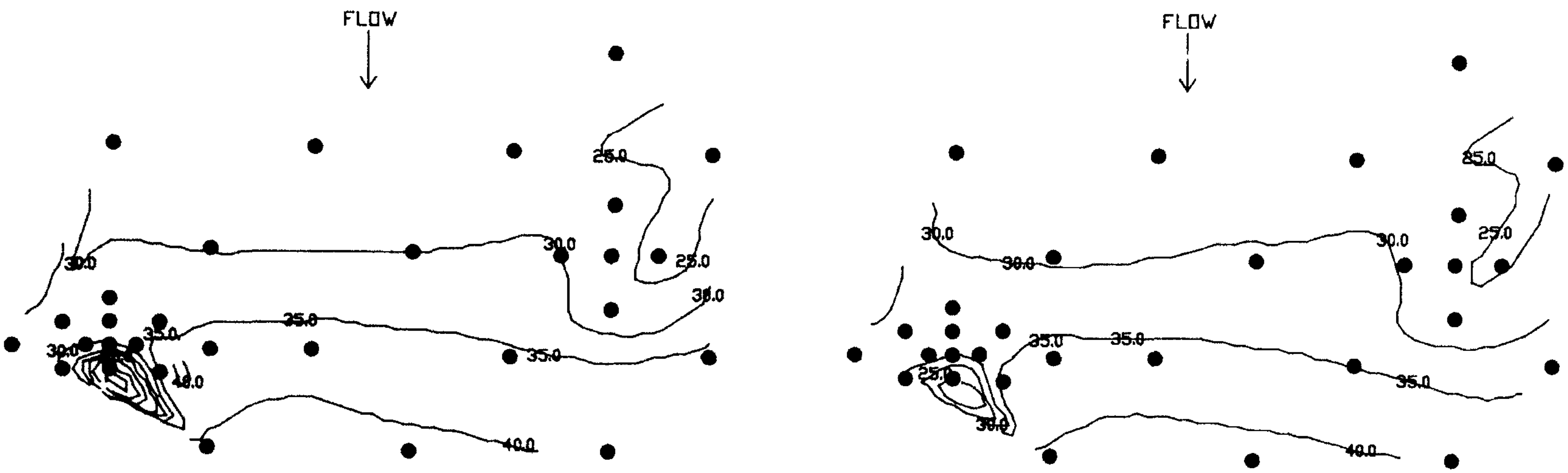
RECORDED 3,493.467 SEC



RECORDED 3,493.569 SEC

NOTE: MINIMUM PULSE OF -17.4 FT
OCCURRED AT 3,493.596 SEC

PRESSURE CONTOURS IN CHRONOLOGICAL SERIES
3493.049 SEC TO 3494.144 SEC
TYPE 2 TRANSDUCER PATTERN, TEST NO.11
DISCHARGE 65,000 CFS
UPPER POOL 1277.1 FT
LOWER POOL 1258.5 FT
GATE OPENINGS: FULL



RECORDED 3,493.706 SEC

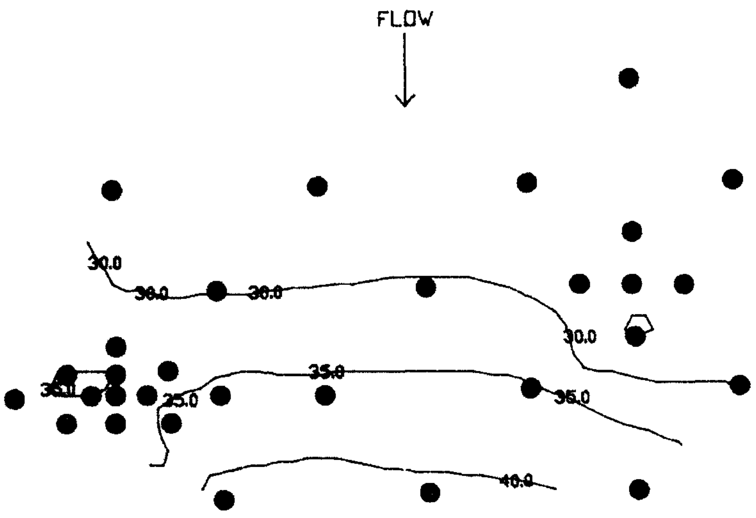
RECORDED 3,493.815 SEC

NOTE: MINIMUM PULSE OF -17.4 FT
OCCURRED AT 3493.569 SEC

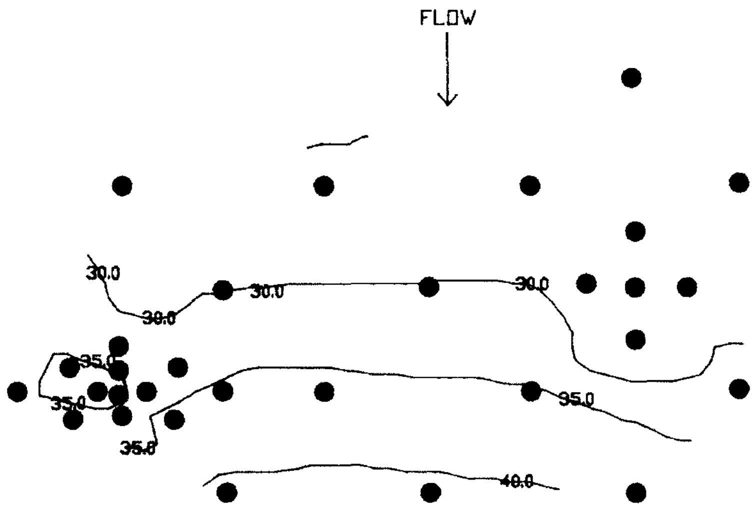
PRESSURE CONTOURS IN CHRONOLOGICAL SERIES

3493.049 SEC TO 3494.144 SEC
TYPE 2 TRANSDUCER PATTERN, TEST NO.11
DISCHARGE 65,000 CFS
UPPER POOL 1277.1 FT
LOWER POOL 1258.5 FT
GATE OPENINGS: FULL

PLATE 12
(Sheet 4 of 6)



RECORDED 3,493.925 SEC

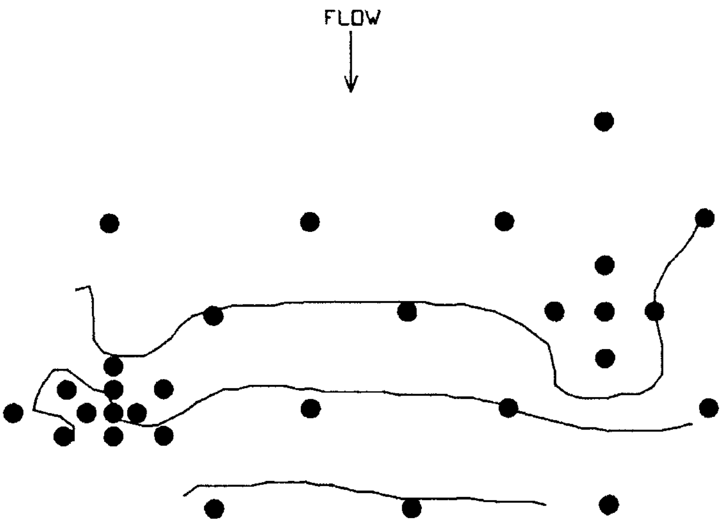


RECORDED 3,494.034 SEC

NOTE: MINIMUM PULSE OF -17.4 FT
OCCURRED AT 3493.569 SEC

PRESSURE CONTOURS IN CHRONOLOGICAL SERIES

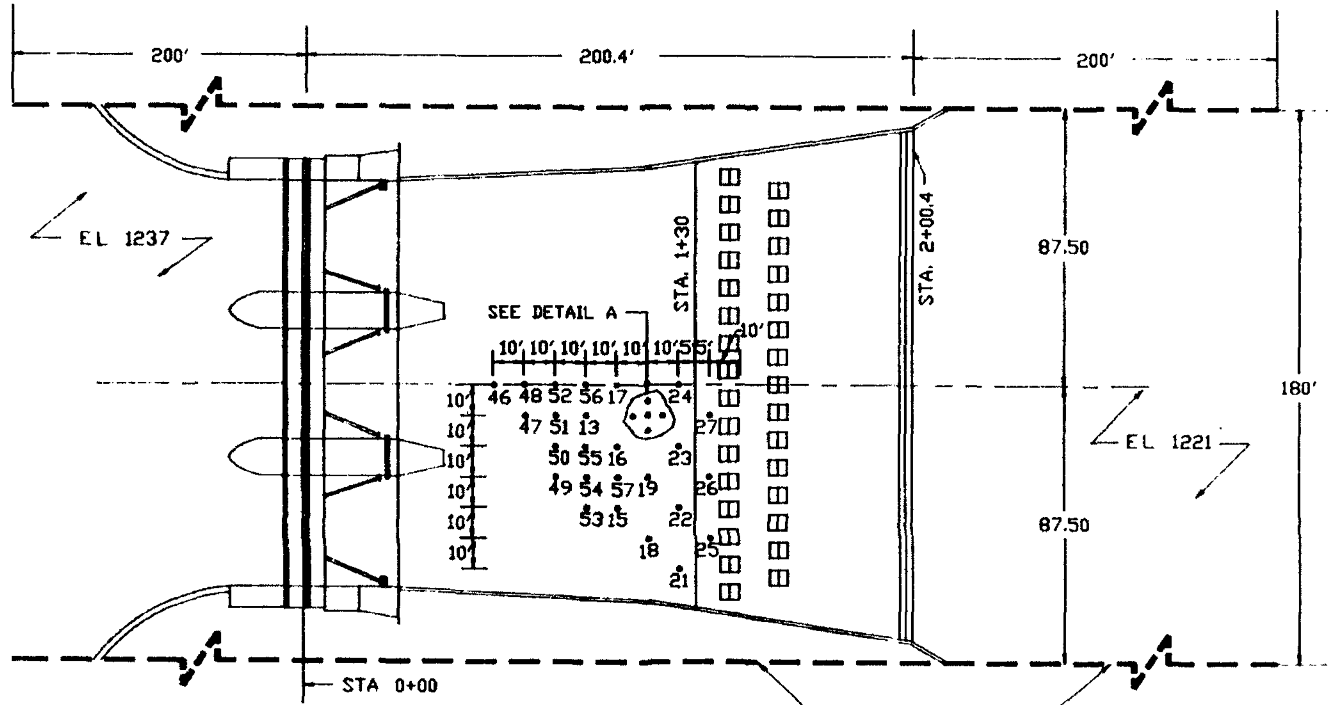
3493.049 SEC TO 3494.144 SEC
TYPE 2 TRANSDUCER PATTERN, TEST NO.11
DISCHARGE 65,000 CFS
UPPER POOL 1277.1 FT
LOWER POOL 1258.5 FT
GATE OPENINGS: FULL



RECORDED 3,494.144 SEC

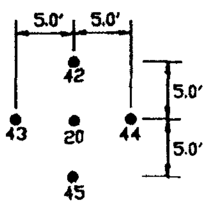
NOTE: MINIMUM PULSE OF -17.4 FT
OCCURRED AT 3493.569 SEC

PRESSURE CONTOURS IN CHRONOLOGICAL SERIES
3493.049 SEC TO 3494.144 SEC
TYPE 2 TRANSDUCER PATTERN, TEST NO.11
DISCHARGE 65,000 CFS
UPPER POOL 1277.1 FT
LOWER POOL 1258.5 FT
GATE OPENINGS: FULL



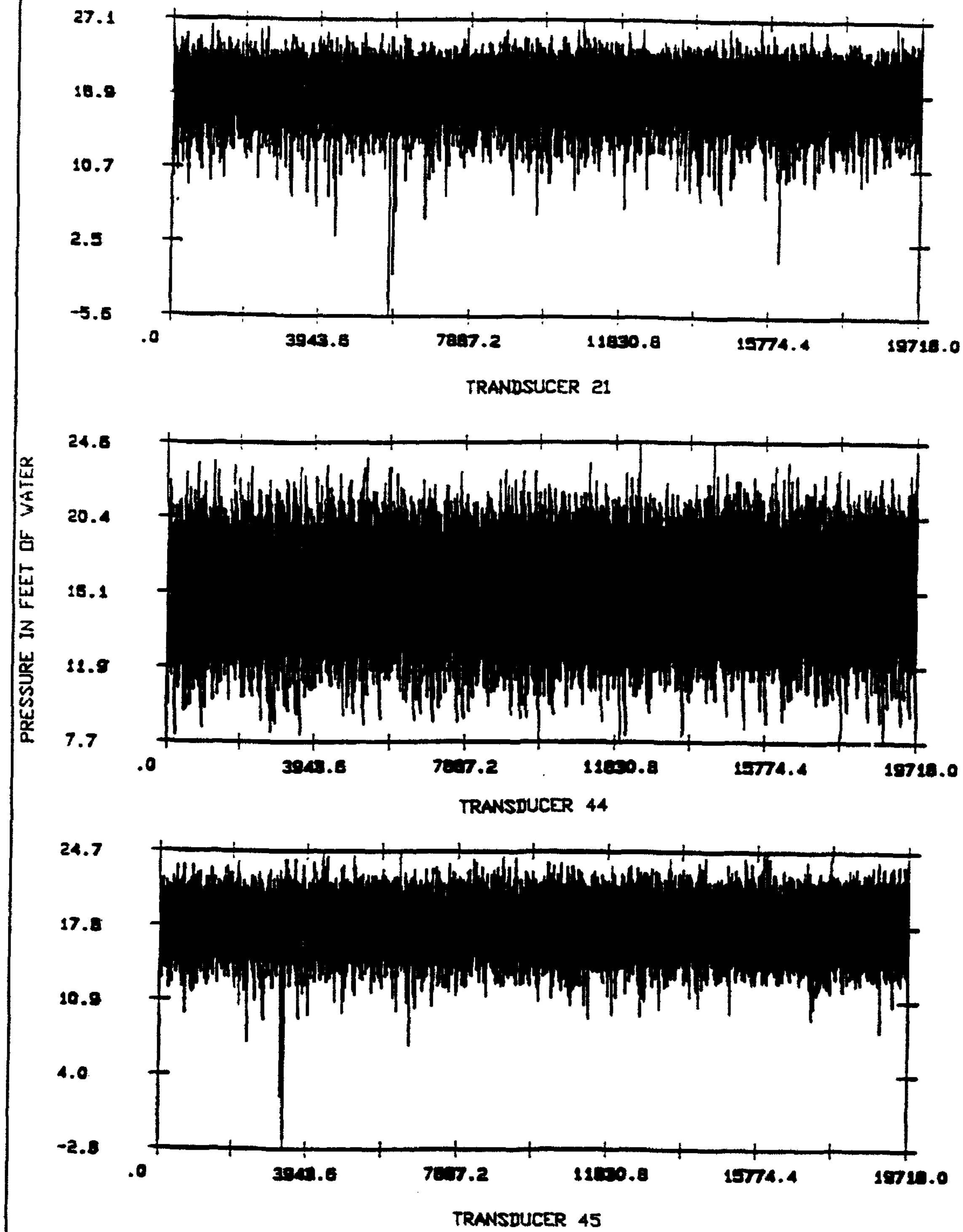
TRANSDUCER ELEVATIONS

NO.	ELEVATION	NO.	ELEVATION
13	1227.30	42	1224.27
15	1227.30	43	1225.03
16	1227.30	44	1223.51
17	1227.30	45	1224.27
18	1224.27	46	1231.86
19	1224.27	47	1230.34
20	1224.27	48	1230.34
21	1224.27	49	1228.82
22	1222.76	50	1228.82
23	1222.76	51	1228.82
24	1222.76	52	1228.82
25	1222.76	53	1227.30
26	1222.20	54	1227.30
27	1222.20	55	1227.30
		56	1227.30
		57	1225.79



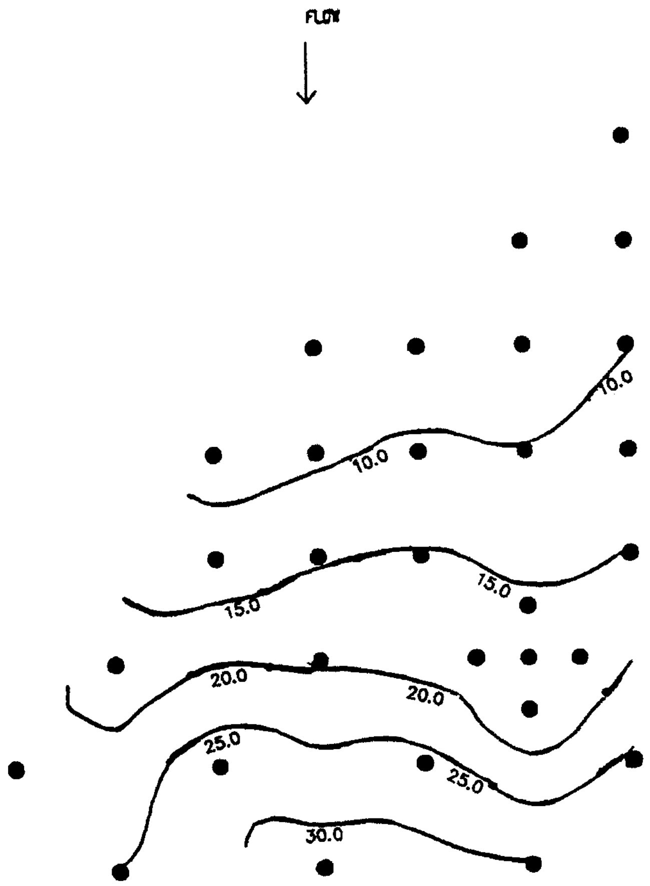
DETAIL A

TRANSDUCER LOCATIONS
TYPE 3 PATTERN



TIME-HISTORY PLOTS
TEST 21
TRANSDUCERS 21,44,45

PLATE 14



TEST NO.19
TIME 17496.79
DISCHARGE 36,000 CFS
UPPER POOL 1273.2 FT
LOWER POOL 1244.8 FT
GATE OPENINGS: GATE 1 CLOSED
GATES 2 AND 3 FULLY OPEN

PRESSURE CONTOURS
TYPE 3 TRANSDUCER PATTERN

TEST NO.20
TIME 10659.27
DISCHARGE 57,000 CFS
UPPER POOL 1279.6 FT
LOWER POOL 1258.5 FT
GATE OPENINGS GATE 1 CLOSED
GATES 2 AND 3 FULLY OPEN

PRESSURE CONTOURS
TYPE 3 TRANSDUCER PATTERN

PLATE 15
(Sheet 2 of 3)

TEST NO.21
TIME: 10593.73
DISCHARGE 19,450 CFS
UPPER POOL 1267.0 FT
LOWER POOL 1241.0 FT
GATE OPENINGS: GATE 1 CLOSED
GATES 2 AND 3 FULLY OPEN

PRESSURE CONTOURS
TYPE 3 TRANSDUCER PATTERN

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Bobby P. Fletcher

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13. ABSTRACT *(Maximum 200 words)*

Model tests of the existing Baldhill Spillway were conducted with symmetrical and asymmetrical spillway gate openings to determine for selected flow conditions the characteristics of the hydraulic pulsating pressures acting on the surface of the spillway chute and stilling basin apron.

The 1:30-scale model simulated the entire width and length of the spillway crest, gates, chute, and stilling basin. The model was capable of simulating various anticipated upper and lower pool elevations and discharges as high as 65,000 cfs. Pulsating pressures were simultaneously measured with 30 surface-mounted transducers located in turbulent areas. Data were collected with a data acquisition system capable of collecting data for prescribed lengths of time and sampling at desired rates.

Tests conducted to determine the vibration characteristics of the model chute and stilling basin indicated that their natural frequencies were too high to influence the magnitude of the measured hydraulic pulsating pressures. Initially, data were collected and sampled for various periods and frequencies to

(Continued)

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determine the appropriate period of time and frequency for measuring the magnitude of the minimum and maximum pressure pulsations.

Test results are presented in tables, pressure contour plots, time-history plots, and videos. The test results provided sufficient information on the magnitude of the potential pulsation pressures acting on the surface of the spillway chute and stilling basin apron to enable design decisions that ensure the integrity of the structure.